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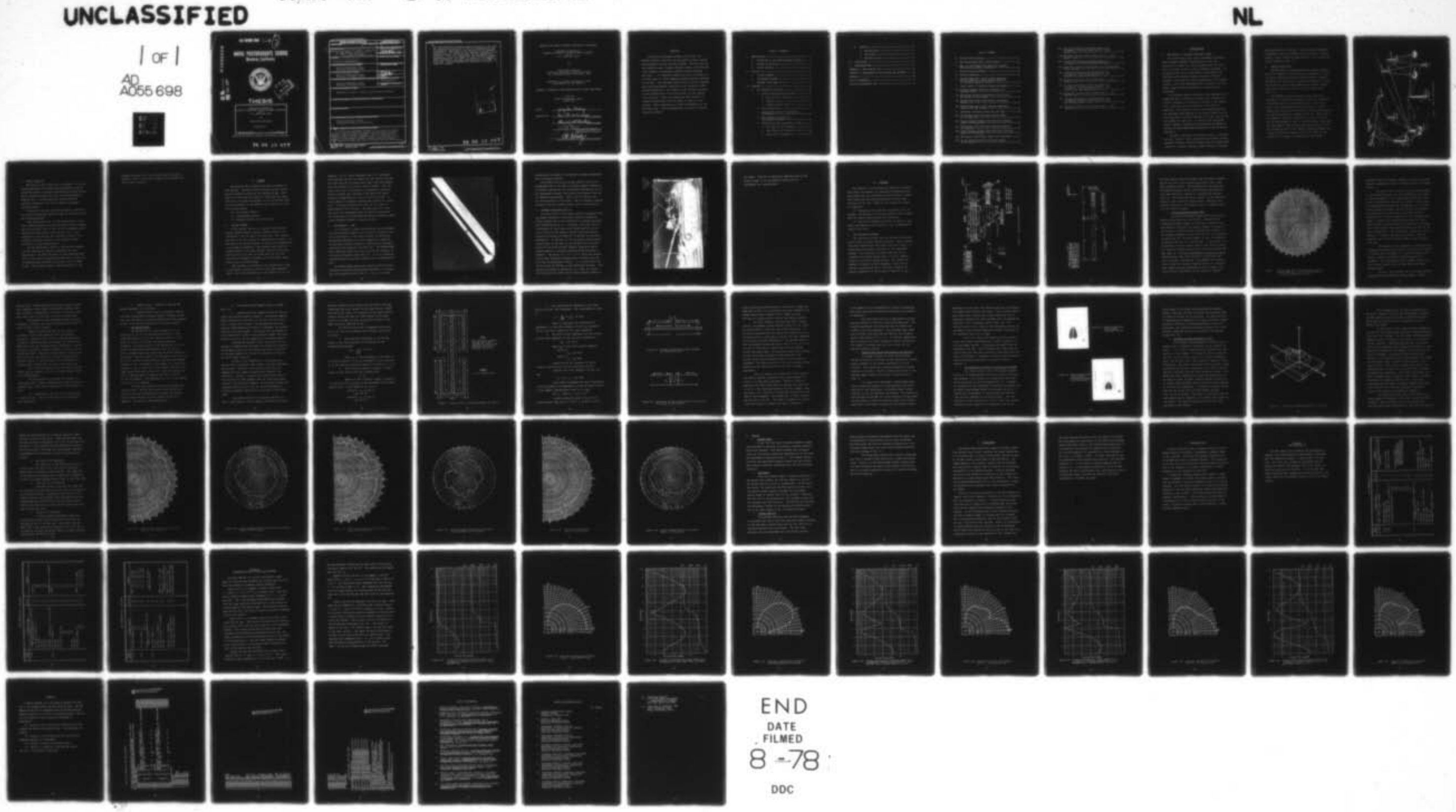

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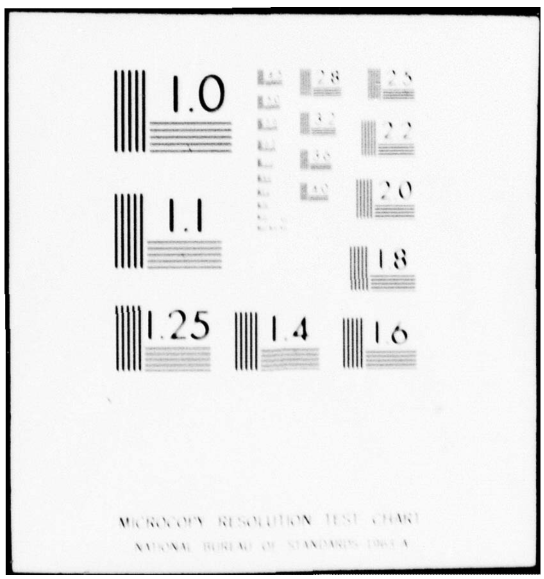
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

RADIATION PATTERNS BY
COMPUTER SIMULATION FOR RMS ANTENNA LOCATIONS
ON A
U.S. ARMY M-60 TANK

by

Jerry Allen McKenzie

March 1978

Thesis Advisor: M. L. Wilcox

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Radiation Patterns by
Computer Simulation for RMS Antenna Locations
on a
U.S. Army M-60 Tank

by

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Lieutenant Commander, United States Navy
B.S., Wisconsin State University, 1965

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS SYSTEMS MANAGEMENT

from the

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ABSTRACT

A potential replacement antenna for use with the RMS/DCS system on the M-60 tank was modeled using a digital electromagnetic antenna analysis program. The M-60 tank was also modeled using a digital Geometric Theory of Diffraction (GTD) program to investigate probable antenna mounting positions. A $\lambda/4$ monopole antenna was used to validate the GTD tank model for three separate possible antenna locations on the tank. The interface capabilities of the two programs were then investigated, resulting in the detection of GTD program limitations. The number of flat surfaces available in the program proved to be insufficient for the complex tank structure. Also, the computation time required increased exponentially with the number of inputs to the program. These limitations are under investigation at the NOSC San Diego. Some recommendations and areas of further study are offered.

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I. INTRODUCTION

A. BACKGROUND OF THE RANGE MEASURING SYSTEM

The United States Army Combat Development Experimentation Command (USACDEC) headquartered at Fort Ord, California is tasked with the operational test and evaluation of current as well as future warfare techniques. To accomplish this mission experimental field problems are conducted under simulated combat conditions which are designed to evaluate the tactical employment of new weapons systems. This field experimentation is carried on at Fort Hunter Liggett Military Reservation located at Jolon, California.

To accurately monitor and assess each experiment as it progresses and to effectively evaluate and critique the results, knowledge of the precise location of all infantry units, vehicular units and aircraft at all times is mandatory. This position data is then communicated from the experiment participants to the central control unit in real time where it can be displayed on a video unit as well as recorded for later use. To satisfy this requirement General Dynamics Corporation was contracted by USACDEC to develop the Range Measuring System/Data Collection System (RMS/DCS).

The RMS is made up of A stations, B units, D stations and one C station. The A stations are positioned in semi-permanent surveyed sites and operate under the computerized control of a single C station, either directly or through

relay/distribution D stations. The A stations interrogate the mobile B units upon command from the central C station. Figure 1 lends a pictorial representation of the entire RMS system interaction (Ref. 1).

B. PROBLEM DESCRIPTION

The RMS system has been plagued with several problems since its inception, resulting in poor reliability. Some of the major contributing factors include improper alignment procedures for the B units, multipath interference, environmental effects such as high temperatures, weather changes and vehicle vibration, as well as poor antenna design (Ref. 2).

The USACDEC consulted the Electrical Engineering Department of the Naval Postgraduate School for assistance in rectifying some of these problem areas. One of the areas given considerable attention was that of antenna design, with several being developed by engineering students as possible replacement candidates (Ref. 3). Additionally, one commercial model was acquired to be tested for suitability when mounted on the U.S. Army M-60 tank. This paper has investigated three possible mounting locations on the tank through the use of two computer modeling programs, one designed to model the antenna itself, the other for the inclusion of a complex environment near the antenna.

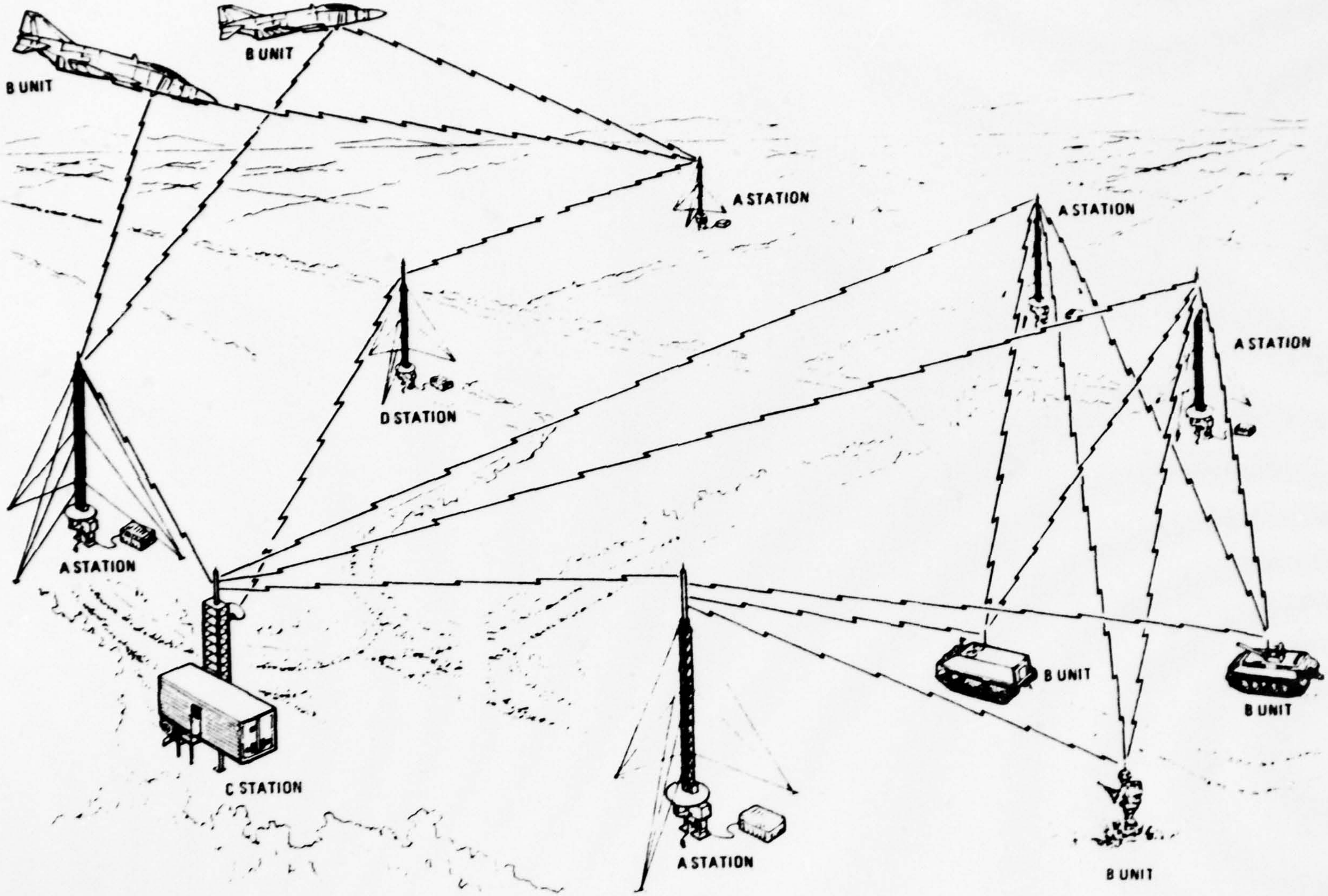


Figure 1. Typical RMS Deployment

C. THESIS OBJECTIVE

The object of this thesis was to determine: 1) if the Phelps-Dodge Model 1065A Mobile Rooftop Antenna could be accurately modeled to produce representative current distribution patterns through the use of the antenna modeling program; and, 2) if the M-60 tank could be modeled accurately through the use of the complex environment modeling program.

The scope of the work included achieving a solution to the antenna positioning problem through the interface of the two modeling programs.

Some limitations were: 1) the unavailability of the tank modeling program on the NPS IBM 360/67 digital computer which necessitated that all data for this program be run on the NOSC San Diego Univac 1100 computer; and, 2) the complexity of the modeled tank structure proved to be an extremely difficult problem for the computer program utilized to do these calculations.

The GTD (Geometrical Theory of Diffraction) program used for modeling the complex environment was first operational at the NOSC San Diego in early February 1978. Prior to this time the program had been used on simple box or pyramidal-type structures consisting of two to three plates. This problem seemed a logical extension of the

program utilizing all of the fourteen plates available, however, it had not yet been attempted and therefore the results were uncertain.

II. PROBLEM

The marginal RMS reliability has been attributed to many factors. The major factors include multipath propagation, hardware reliability, and antenna design. This paper will deal with the problem of verifying the compatibility of an antenna replacement for use on the M-60 tank in the environment of the FHLMR and will therefore look at the following areas:

(1) The present antenna

(2) A replacement antenna

(3) Antenna position on the M-60 tank

A. PRESENT ANTENNA

At the present time the U.S. Army is utilizing the General Dynamics SN-007 antenna, commonly known as the "Broomstick," for the RMS on the M-60 tank. This antenna has been in use for a period of approximately 10 years. It was part of an initial contract for which most documentation is no longer in existence. The antennas, which were included as part of the total package, varied in cost from $807 each for 12 in 1974 to $1,466 each for 6 in 1976. There was no competitive bidding on the individual items, only on the total RMS package.

This antenna is positioned on the forward left corner of the turret, directly in front of the Tank Commander's hatch. Due to the composition of the antenna (3/4 in. in

diameter, 1/16 in. thick fiberglass and 5 ft. in height), the rough-type terrain over which the tank travels, and the fact that the tank is driven under trees, the feed elements are often broken loose from the driven element. This can cause total loss of continuity or intermittent operation. Several antennas were returned to the vendor for repair which was accomplished at a cost of $55 to $70 each. A second group of inoperable antennas was returned at a later date. The vendor estimated the unit cost of repair at approximately $750 to $1,000. The Army chose not to pay this price and subsequently had the antennas analyzed by the technicians at the NPS Monterey Antenna Laboratory where a more economical method of repair was used.

B. REPLACEMENT ANTENNA

In an attempt to reduce the maintenance and replacement costs and therefore improve the life cycle costing, as well as the reliability of the overall system, the Electrical Engineering Department at the NPS suggested a commercial off-the-shelf antenna designed to withstand the punishment associated with mounting on an M-60 tank. The Phelps-Dodge Model 1065A was chosen as it was the only one available in the required frequency range (Fig. 2). It is a vertically-polarized modified full-wave monopole with a spring-mounted base.

The Phelps-Dodge antenna was tested by the Electronic Industries Association Engineering Department in accordance with EIA Standard RS-329-1 (Ref. 4). Due to its sturdy

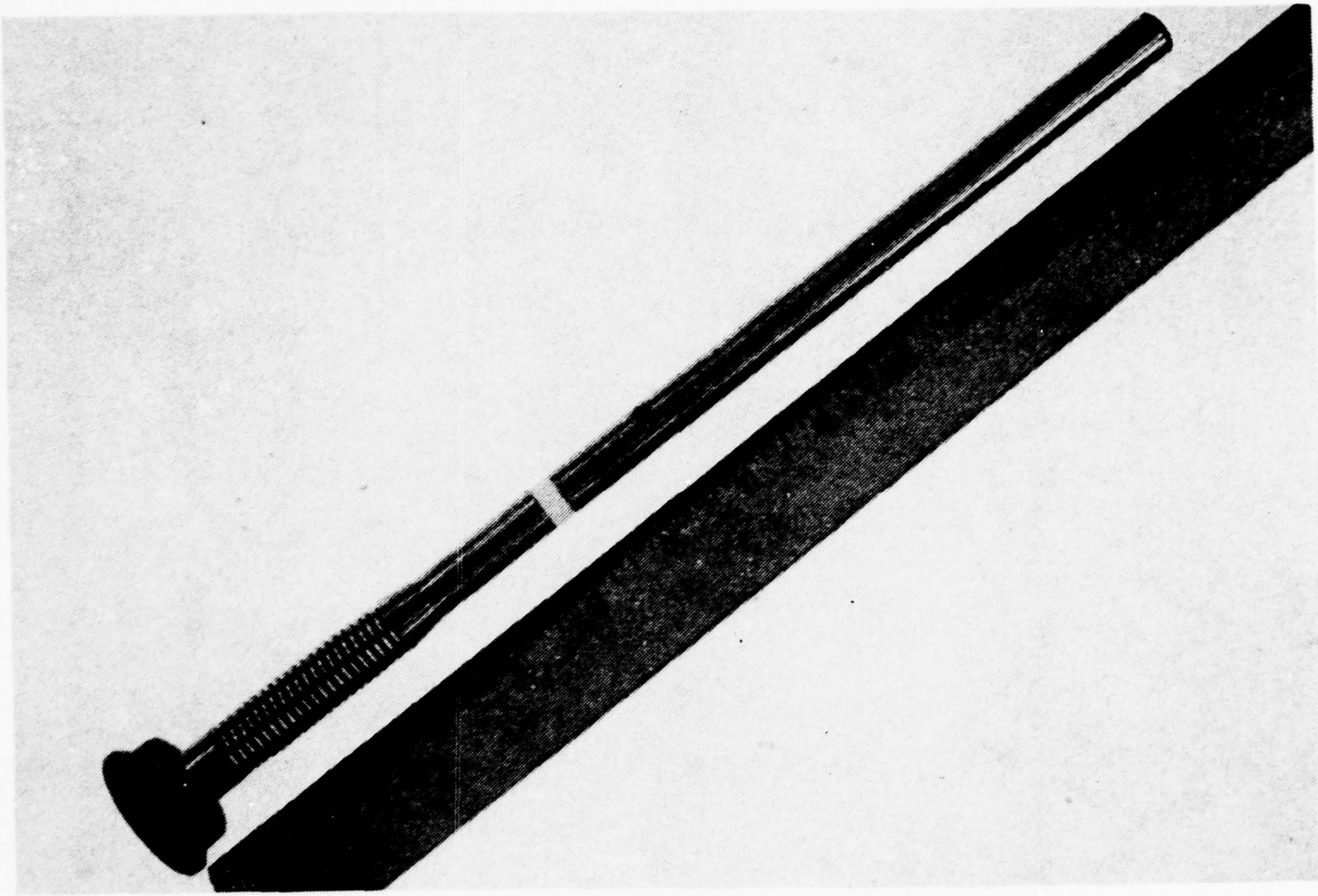


Figure 2. The Phelps-Dodge Model 1065A Antenna

construction the antenna is projected to remain maintenance-free if properly mounted.

An in-depth life cycle costing analysis could not be accomplished due to the lack of accurate support figures on the present antenna and the non-existent maintenance cost of the replacement antenna; only initial procurement costs can be compared realistically. With a cost of $29 per unit - $21 for quantities of 50 or more - the LCC remains a quantum reduction from the original antenna that it would replace.

C. ANTENNA POSITIONING ON M-60

As noted in Ref. 5 the antenna patterns propagated from the present antenna at its present location displayed an erratic pattern due to the possibility of masking and multipath interference (Fig. 3). Therefore, this study set out to determine if there was a more optimal position on the tank to place an RMS antenna, thereby increasing system reliability through the reduction of masking and multipath propagation. In addition to the two present antenna mounting positions on the tank, it was decided that the feasibility of utilizing the MIPS (Modular Integrated Pallet System) pallet as a possible mounting position should be examined. The pallet is a 3 x 2 x 1 ft. metal box containing the RMS electronics package which interfaces with the M-60 tank instrumentation system. It is located above the 105 mm cannon and mounted on the searchlight brackets. This places the antenna an additional 9 in. above the turret, with the gun level, which should reduce masking created by

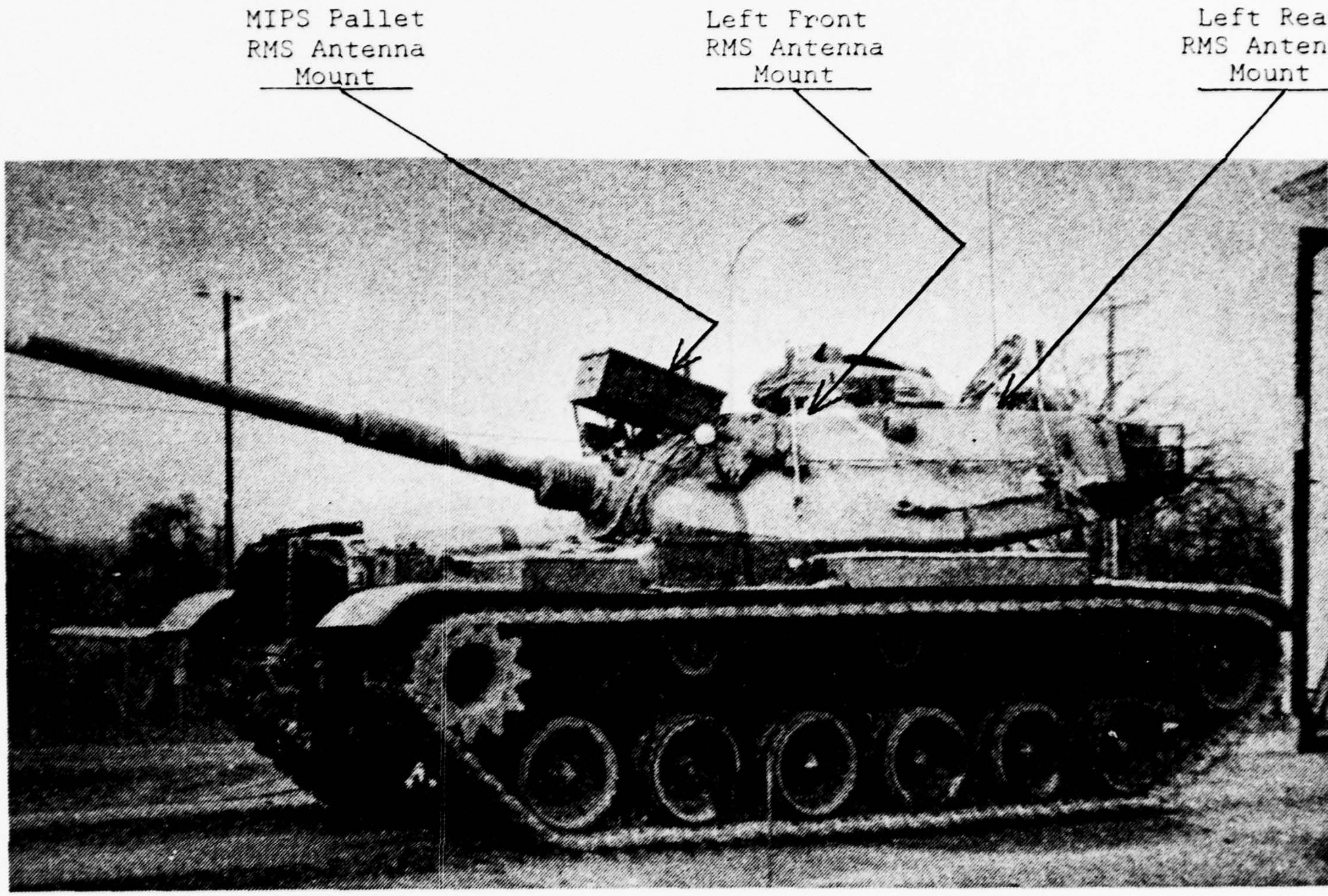


Figure 3. The U.S. Army Model M-60 Tank With Possible RMS Antenna Locations Indicated

the cupola. This was of particular importance due to the reduced height of the replacement antenna and its requirement for a ground plane.

III. APPROACH

The approach to this problem was therefore to numerically model the antenna, run simulated configurations and then compare the most favorable position results to actual field tests with the antenna positioned at those same locations on the tank. There are two reasons for taking this approach:

(1) Simulation is an excellent management tool for examining the problem as critical parameters can be changed with the results noted quickly and effectively.

(2) The use of simulation reduces the amount of man-hours, equipment and fuel required to run a comprehensive study in the field.

A. THE SIMULATION PROGRAMS

The simulation process involved modeling the antenna and the tank to obtain radiation patterns. These patterns were then compared with the actual field test results to demonstrate the validity (accuracy) of the simulation program. This resulted in no small task due to the complexity of antenna design (Fig. 4) and the complete absence of electrical specifications. The antenna was designed to operate in three frequency ranges with an over-all coverage from 806 to 937 MHz by changing the physical dimensions of the antenna as depicted in Fig. 5.

"B" DIM	"C" DIM	FREQ
.880	1.355	806-866
.992	1.188	825-890
.939	1.125	872-939

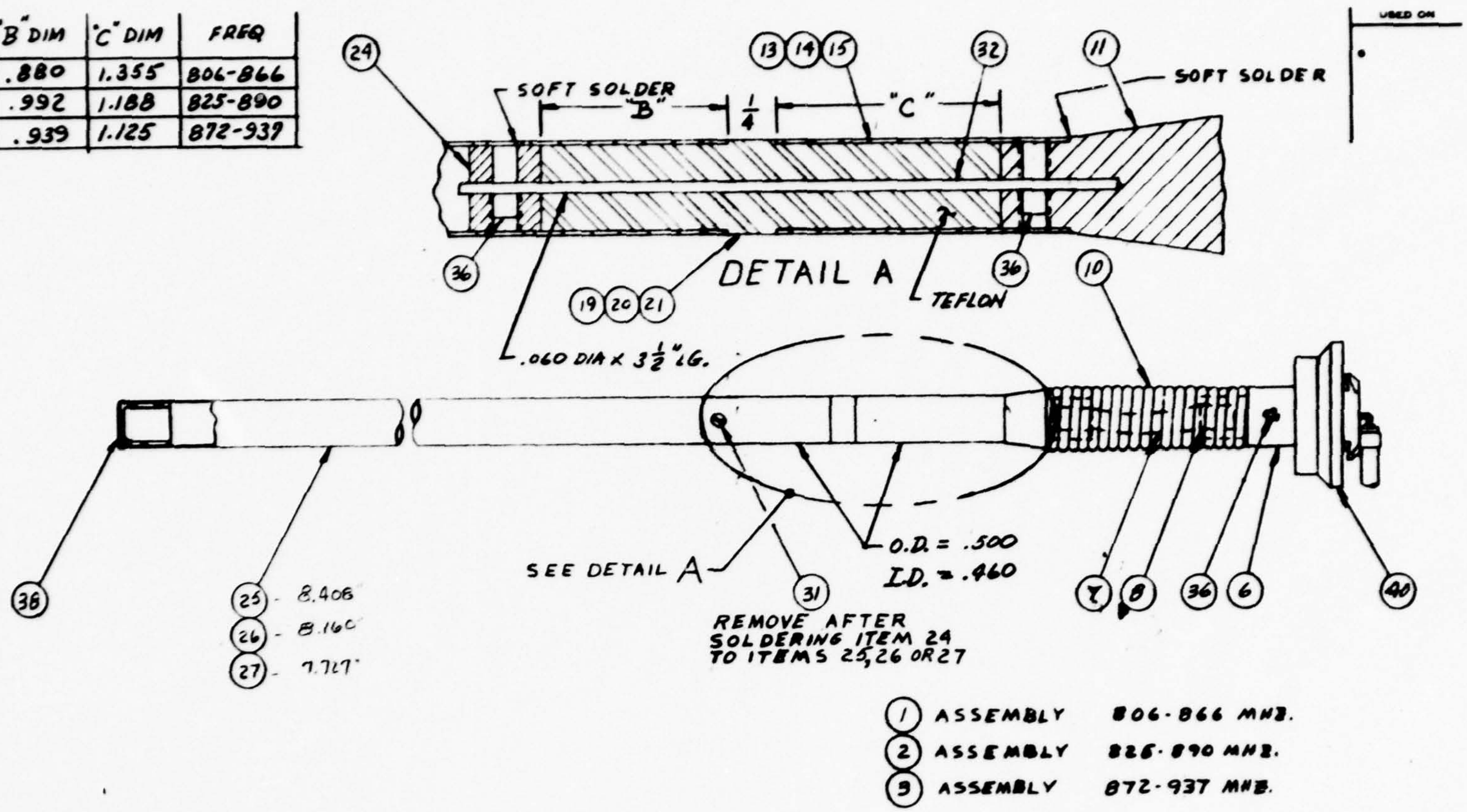


Figure 4. Antenna Design Breakdown

FREQ.	L_1 IN INCHES	(NOM) L_2 IN INCHES
806-866	8.408	5.293
825-890	8.160	5.126
872-937	7.727	5.044

USED ON

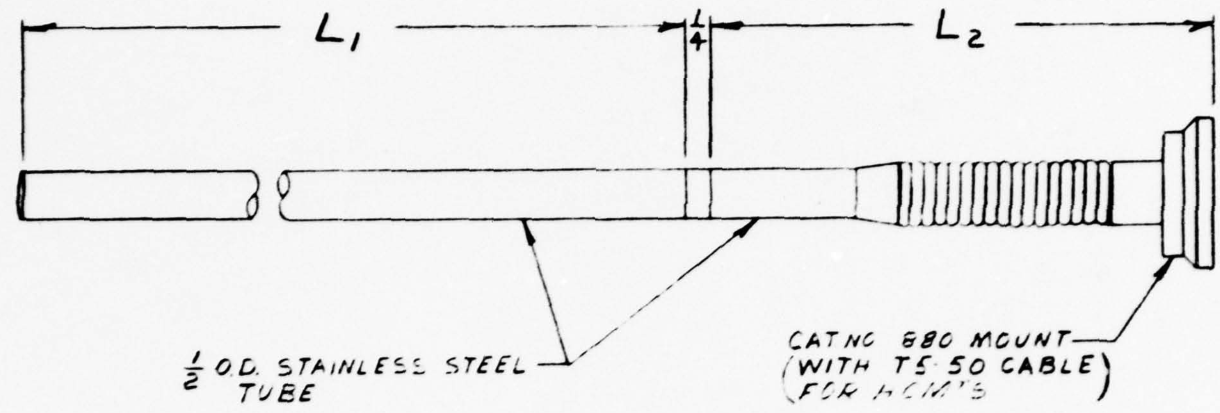


Figure 5. Antenna Dimensions

The only antenna pattern available from the vendor, however, was one run over a 140 cm ground plane and in one of the lower frequency ranges. The assumption was then made that the higher frequency version would maintain approximately this same pattern as compared to a quarter-wave monopole (Fig. 6). The lobing structure, however, is very frequency-sensitive over this finite ground plane. Therefore, the patterns achieved in the simulation may not compare exactly with the vendor's pattern.

1. Antenna Modeling Program (AMP)

The Antenna Modeling Program (AMP) was developed under a joint Army, Navy and Air Force contract by the Information Systems Company of Menlo Park, California for the purpose of employing the digital computer to assist in the solution of antenna current distribution problems. It was designed primarily for use with thin wire or cylindrical antennas that are a few wavelengths, or less, in length at frequencies from VLF into the UHF band. It has proven to be an extremely accurate antenna analysis tool which is based on a rigorous integral equation for solving the antenna current (Ref. 6). This was accomplished by numerically using techniques that have been optimized for efficiency and accuracy within a few percent. The approach used remains valid through the resonant frequency region of a structure where common limiting approximations are no longer valid. A more detailed description of the "method of moments"

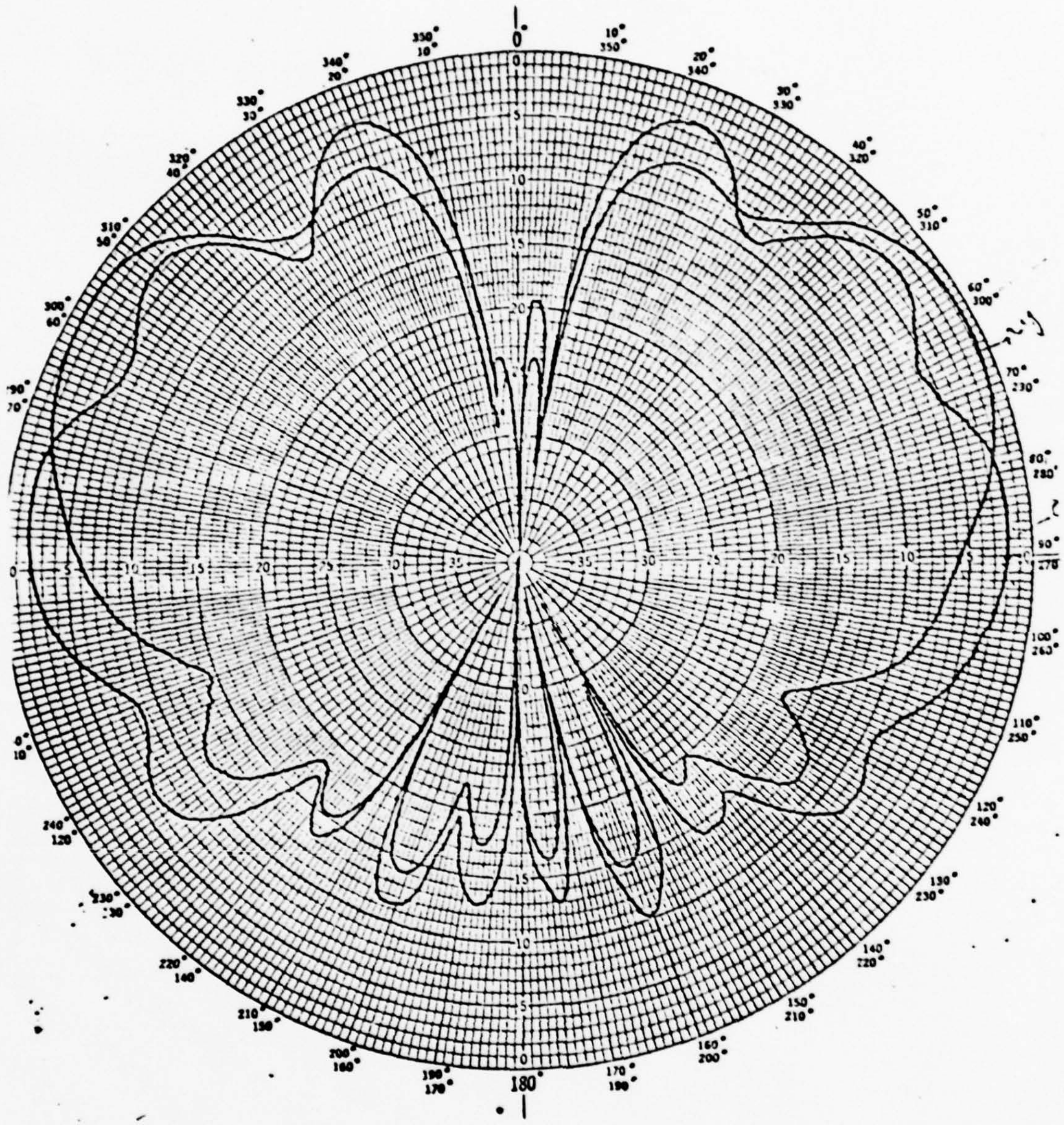


Figure 6. Phelps-Dodge Model 1065A Antenna Radiation Pattern Taken on a 140 cm Ground Plane vs $\lambda/4$ Monopole Radiation Pattern

procedure used by the digital computer to solve the antenna currents, impedances and the far field patterns is contained in Ref. 7.

The AMP is quite versatile in that other antennas or conducting structures that can be modeled as wire grids in the environment of the antenna being tested that could affect its performance may also be modeled. In this case, the communications antenna was considered to be out of the tested antenna environment and was therefore not modeled. The program also has provisions to include series or parallel R-L-C circuits on any part of the structure, other types of loading, and non-radiating networks and transmission lines connecting parts of the antenna or structure. All of these options were exercised before arriving at the final configuration. The program also allowed for the inclusion of a ground plane under the antenna. This was essential due to the conducting surface of the all-metal M-60 tank.

The program has the capability of modeling either a transmitting antenna, with several variations in location of voltage source available, or a receiving antenna with either a linear or elliptically-polarized plane of incidence. An infinitesimal current element source could also be used, however, all runs were made utilizing a voltage source.

All quantities commonly used to evaluate antenna performance are available from this program. Outputs

derived from a transmitting antenna include antenna current, input impedance, power budget and radiation patterns with gain available in components of vertical, horizontal, major axis, minor axis or total gain, as well as average gain.

The program has many additional options and idiosynchrasies, however, this brief description was limited to those utilized in this problem.

Numerical antenna analysis has two sources of inaccuracy, those being numerical error and modeling inaccuracy. Numerical errors arise in the AMP algorithms on digital computers having word lengths less than 48 bits. When such is the case double-precision arithmetic is used in critical calculations, thereby reducing the error to an insignificant value. Modeling accuracy depends upon how well the user defines the antenna or structure being modeled. The main efforts in this study went into achievement of a representative antenna model as will be described below.

All of the AMP computer runs were made on the IBM 360/67 digital computer at the W. R. Church Computer Center at the NPS Monterey.

The data required to describe the antenna, its environment and to request computation was input by means of punched cards. This card set consisted of three types of data:

a. Description of the run - one or more cards to label the run. These were printed at the beginning of each output run.

b. Geometry cards - required to specify the physical geometry of the antenna.

c. Program control cards - utilized to specify electrical parameters including frequency, loading, excitation, and calculation of antenna currents and field requests. See Ref. 6 for detailed description of the data cards.

2. The Antenna Model

The antenna has an over-all length of 13 in. including 1/2 in. for the mounting base (Fig. 2). The radiating portion is 12-1/2 in. which is equal to 0.3175 meters or 0.9723λ at 918 MHz, the system operating frequency. The lower section of the antenna has a 1/2 in. plastic non-radiating mounting base with a 1/2 in. by 5/8 in. diameter base ring connecting the driven element to the source. This base ring is also attached to the 2-1/6 in. by 5/8 in. diameter spring which has a metal braid running internal to it. The purpose of the spring is to allow the antenna to flex if struck by a solid object, such as a tree limb, rather than bend or break off. Atop the spring is a 7/16 in. section which is tapered from 5/8 in. down to 1/2 in. in diameter. The remaining 9-1/2 in. of the antenna is all 1/2 in. in diameter.

To model the antenna, it was first divided into three sections. The top and bottom of each section was joined to the next and located in Cartesian coordinates. Each of these sections was then further divided into segments. Two rules of thumb applied here:

a. Electrically each segment should be longer than 0.1λ.

b. Geometrically each segment should be twice as long as the antenna radius or greater. The antenna segments should therefore be thin wire, or rod like vice short disc like, or poker chip in shape. The program uses an interpolation scheme during the solution to represent the current variation over each segment. The current on each segment is then interpolated to that on each adjacent segment and interpolated to zero on the end segment on a continuous antenna.

Although the antenna's lower section was 1/8 in. greater in diameter than the upper two sections and included the irregular surface of the spring, they were all modeled at the same diameter for the sake of simplicity and due to the short length involved.

Because of the complexity of the antenna, the geometry was altered many times before a suitable simulation was achieved. Sections 1 and 3 were divided into five segments and nine segments respectively throughout the simulation. Section 2, however, was reduced from seven to five and then to three segments with the teflon gap always located in the mid-center segment, as the antenna radius was increased from 1/32 in. to 1/4 in. while investigating different parameters which will be discussed in more detail below.

The center section of the antenna (detail A of Fig. 4) was assumed to have a current flow which, following

the outer surface of the antenna from the base to the gap, flowed down the inner surface of the lower section, flowed into and up the center core conductor to the upper shorted section, across and down the inner surface of the upper section of the gap, and then up the outer surface of the upper section as depicted in Fig. 7.

To arrive at the value of impedance seen across the 1/4 in. gap in the antenna the following calculations were made:

a. The equivalent wavelength of the 918 MHz signal in the teflon material was determined by the following relationship:

$$\lambda_{tl} = \frac{\lambda_o}{\sqrt{\varepsilon_r}} = 8.878 \text{ in.}$$

Where λ_{tl} is the wavelength of the signal in the teflon material, λo is the wavelength in free space and ε_r is the relative dielectric constant of teflon ($\varepsilon_r = 2.1$).

b. The electrical length in degrees, or phase shift, in each section was then determined by:

$$\theta = \beta l$$

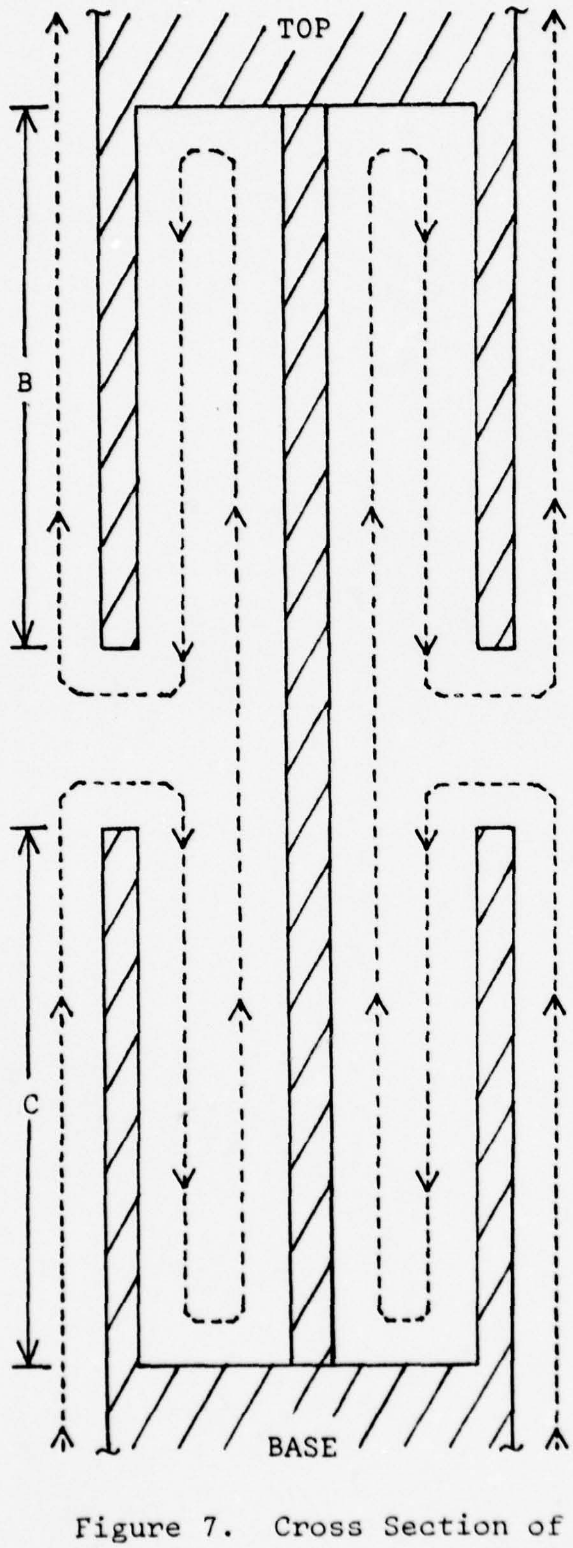
Where θ is the electrical length in degrees, β is the ratio of 2π radians to the wavelength in the teflon material and l is the length of the section.

Section B, $l_B = 0.939$ in.

$\theta_B = 38.10^\circ$

Section C, $l_C = 1.125$ in.

$\theta_C = 45.61^\circ$



Note

The dielectric material filling the B and C cavities is teflon with relative dielectric constant (ε_r) of 2.1.

Legend

------ current flow

Figure 7. Cross Section of Antenna Through Gap Region

c. The characteristic impedance of the transmission line was then determined. The relationship is given by:

$$Z_o = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{D}{d} \simeq 83 \text{ ohms}$$

Where Z_o represents the characteristic impedance, D is the inner diameter of the outer conductor and d is the outer diameter of the inner conductor.

d. The short circuit impedance for each section and the total impedance for the line was determined by:

$$Z_{sc} = {}_jZ_o \tan \theta$$

Where Z_{sc} is the short circuit impedance:

Section B

$$Z_B \simeq {}_j65 \text{ ohms}$$

Section C

$$Z_C \simeq {}_j85 \text{ ohms}$$

Figures 8A and 8B illustrate the short circuit sections B and C and the equivalent circuit.

Therefore the total impedance for the line was:

$$Z_1 = Z_B + Z_C = {}_j150 \text{ ohms}$$

This value of impedance was then incorporated into the program as an admittance to load the center section at the segment corresponding to the 1/4 in. gap.

For $Z_1 = {}_j150$, $Y_1 = -{}_j6.6 \times 10^{-3}$

Several different values of $Z_1(Y_1)$ were tested however from ${}_j15(-6.6 \times 10^{-2})$ to ${}_j2500(-4 \times 10^{-4})$,

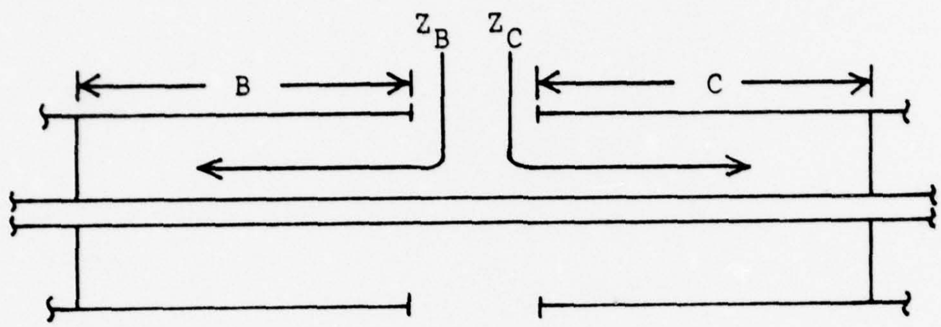


Figure 8A. Antenna Diagram Indicating Impedance for Sections B and C

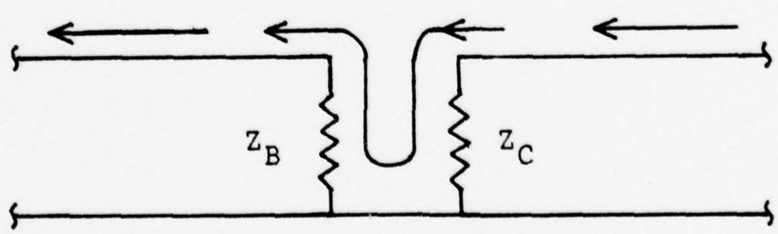


Figure 8B. Equivalent Two-wire Transmission Line Circuit of the Gap in the Antenna

while varying the antenna radius in the effort to bring the VSWR down to below 2:1 and matching the input impedance (the antenna design input impedance was 50 ohms) and also arriving at a representative current distribution pattern.

The first computer runs were made with a single section, ten-segment unloaded antenna located 1/2 in. above the ground plane to allow for the plastic base mount. It was later discovered that the antenna was required to be on the ground plane to accurately calculate the input impedance and the resulting VSWR (Appendix A). The antenna radius of this ten-segment antenna was varied from 1/32 in. to 1/4 in. at 1/32 in. intervals to monitor the effect on antenna current and phase angle. The expected results were achieved in that the current increased in amplitude while the vertical power gain decreased slightly as the radius was increased. The peaks and nulls in the vertical gain pattern remained in the same position but were not as sharply pronounced.

Next the antenna was divided into three sections and network loading introduced at the center segment of section 2 as previously mentioned. Different values of impedance were then tested while increasing the radius out to 1/4 in. The operating frequency was also changed - plus and minus 1 and 2 percent - to check the sensitivity of the VSWR in this parameter. This change was 0.5 while increasing from 900 to 936 MHz. The number of segments in section 2 was also reduced to comply with rule of thumb No. 2.

A few examples of the representative current distributions with their associated vertical gain patterns are presented in Appendix B.

The final model was felt to approximate the real antenna patterns as closely as could be accomplished. All program requirements were satisfied and the network was loaded at $-j150$ ohms impedance. The resulting input impedance was within tolerance and the VSWR was only slightly greater than desired at 2.6 to 1. The antenna segmentation data coordinates and their respective current distribution were output on punched cards for use as input for the radiation pattern program.

3. Thermovision Current Distribution Verification

An attempt was made to verify the resulting current distribution utilizing the AGA Thermovision Infrared camera equipment in the antenna laboratory at the NPS Monterey. This system was an optical-mechanical scanning technique to produce a visible, raster-line picture of the infrared image formed by the camera's infrared optics (Ref. 8).

To conduct this experiment a Phelps-Dodge Model 1065A antenna was mounted on a flat aluminum plate with a backdrop of five thicknesses of resistive paper located adjacent to, but not touching, the antenna. The antenna was then radiated at 918 MHz for a short interval of time allowing the antenna to heat the resistive paper with radiated power which could then be detected by the infrared camera.

Therefore in areas where the radiated power was the greatest the highest heat transfer took place. After several adjustments were made a display was received which was felt to adequately represent the power radiated and a photograph was then made of this isothermal pattern (Fig. 9A). The horizontal band at the bottom of the photograph exhibits ten isotherms in the selected temperature window, increasing in $5^{\circ}C$ increments from left to right.

The 1/4 in. gap in the antenna was then shorted across with copper conducting tape to make it appear as a full wavelength antenna. A photograph was again taken for comparison (Fig. 9B). The photographs were taken from the color monitor and have been converted to halftone black and white for printing. A comparison of these results with the current distribution patterns is included as part of Appendix B.

4. GTD (Geometrical Theory of Diffraction) Program

The latest "state of the art" program available for use in investigating UHF scattering effects associated with antennas in the presence of complex plate and cylindrical structures is the GTD program (Ref. 9). Although the program which was developed by Ohio State University for the Naval Ocean Systems Center was designed for use in a complex ship environment, it was believed that the M-60 tank could be simulated in a similar fashion. The code simulates a metal structure by a set of finite flat plates situated in such a manner as to appear as close to the

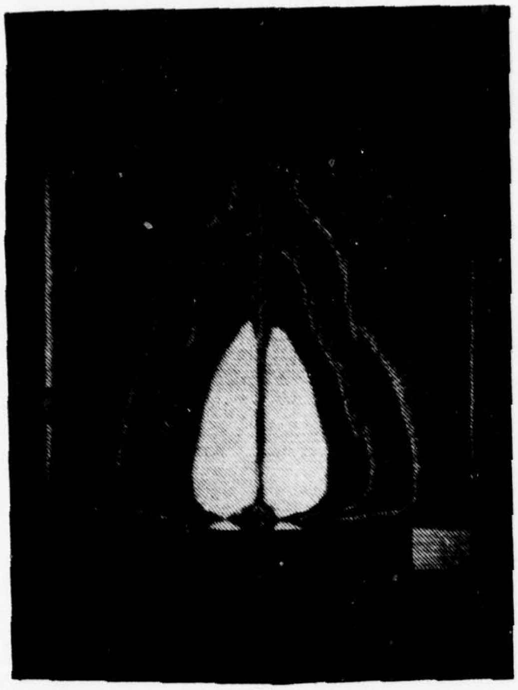


Figure 9A. Phelps-Dodge Model 1065A Antenna Isothermal Pattern

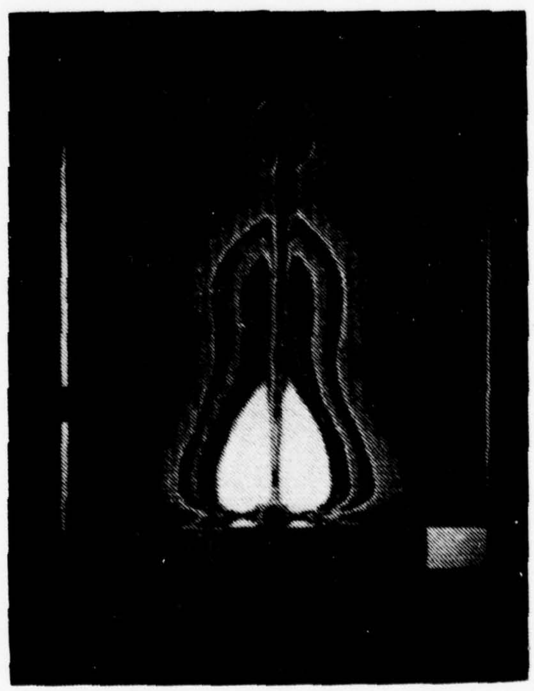


Figure 9B. Phelps-Dodge Model 1065A Antenna Isothermal Pattern with Gap Shorted

actual shape of the object being simulated as possible, forming a box-like structure for which the scattering from one plate to another can be accounted. The code does this by calculating all combinations of singly reflected, doubly reflected, diffracted, diffracted-reflected, reflected-diffracted, and reflected-diffracted-reflected rays on all surfaces, edges and corners in the path of the radiated energy (Ref. 10).

5. Modeling the Tank Structure for GTD

The structure being simulated is divided into no greater than 14 surfaces (a limitation of the current GTD code). Each of these 14 plates must be perfectly flat and can have up to 6 corners. To divide the tank or structure into several flat plates, three 1/8 in. scale elevations - front, top and left side - were acquired to assist in their formulation. The area of the turret with the cupola, cannon and MIPS pallet was then traced over in as close an approximation as possible with the above limitation in mind. The cannon was later eliminated to reduce the calculation set. As there are three different possible antenna locations to be tested, three different sets of plate data were required to run each site separately. A Cartesian coordinate system was then set up with the left rear antenna position (Fig. 10) as the origin. Each plate for the three runs was then defined by the location of its corners with respect to the origin. The other two antenna locations were also specified in this manner.

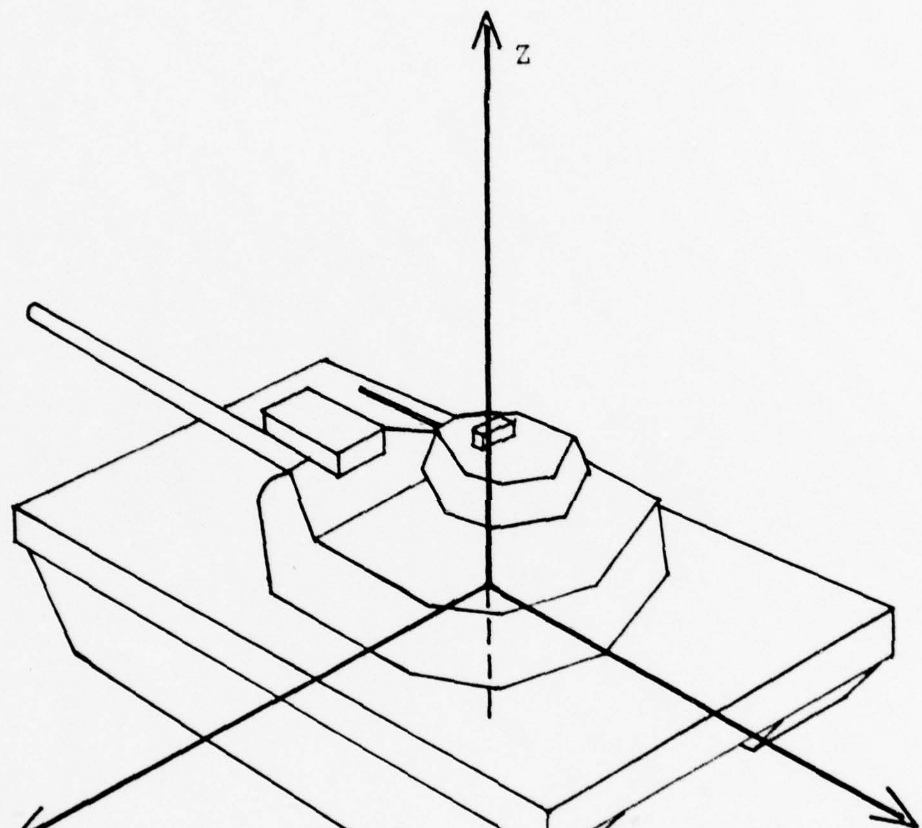


Figure 10. Cartesian Coordinate System for the Tank

This program had not yet been converted to the IBM 360/67 computer for use at the NPS Monterey, therefore the AMP current outputs were taken to the NOSC San Diego where they were input into the operating GTD on their UNIVAC 1100 system.

As this was the first complex system attempted on the new GTD code several minor procedural problems developed which had to be overcome. The AMP output describing antenna segment location, orientation and excitation was accepted without a problem. Formatting problems were encountered with the plate geometry input requiring modification. Three plates were rejected by the computer as not being flat and had to be changed. The greatest problem encountered, however, is one which has not yet been overcome, that being the inordinate amount of computer time required to run a single pattern. After several attempts were made at increasing amounts of time, with no output after 20 minutes, the problem was terminated. After some calculations were made it appeared that a single run would require in excess of one hour of computer processor time. It was then determined that the number of antenna segments would have to be reduced as the CPU time increased at least by a factor of the square of the number of segments.

The decision was then made to run patterns on a single segment $\lambda/4$ monopole in the three possible antenna locations. This was done to see if the modeled tank structure would cause disturbances in the radiation patterns

similar to those produced by an antenna mounted at these locations in actual field tests. Three patterns were run for each location at elevations of 0°, 10° and 20° above the the horizon. These patterns yielded satisfactory results over the portions of the tank that were modeled, therefore a representative run from each location was included as follows:

a. Left Rear at 20° Elevation

The right side of the pattern only was included as the left side of the tank was not accurately modeled with the antenna in this position. The right side of the pattern does however bear a significant resemblance to that of an actual antenna pattern (Fig. 11A and Fig. 11B).

b. Left Front at 0° Elevation

From this position also only the right side of the pattern was observed as the left side of the tank was not accurately modeled. Disruptions were present in the computer pattern which indicate that the modeled structure representing both the MIPS pallet and the cupola have an effect on the pattern as is also present in the actual run (Fig. 12A and Fig. 12B).

c. Pallet at 0° Elevation

At this location disturbances were also observed which would indicate the modeled structure was approaching that of the real tank. Once again only the right 180° of the pattern was included as the left side of the modeled structure lacked the detail to produce accurate results (Fig. 13A and Fig. 13B).

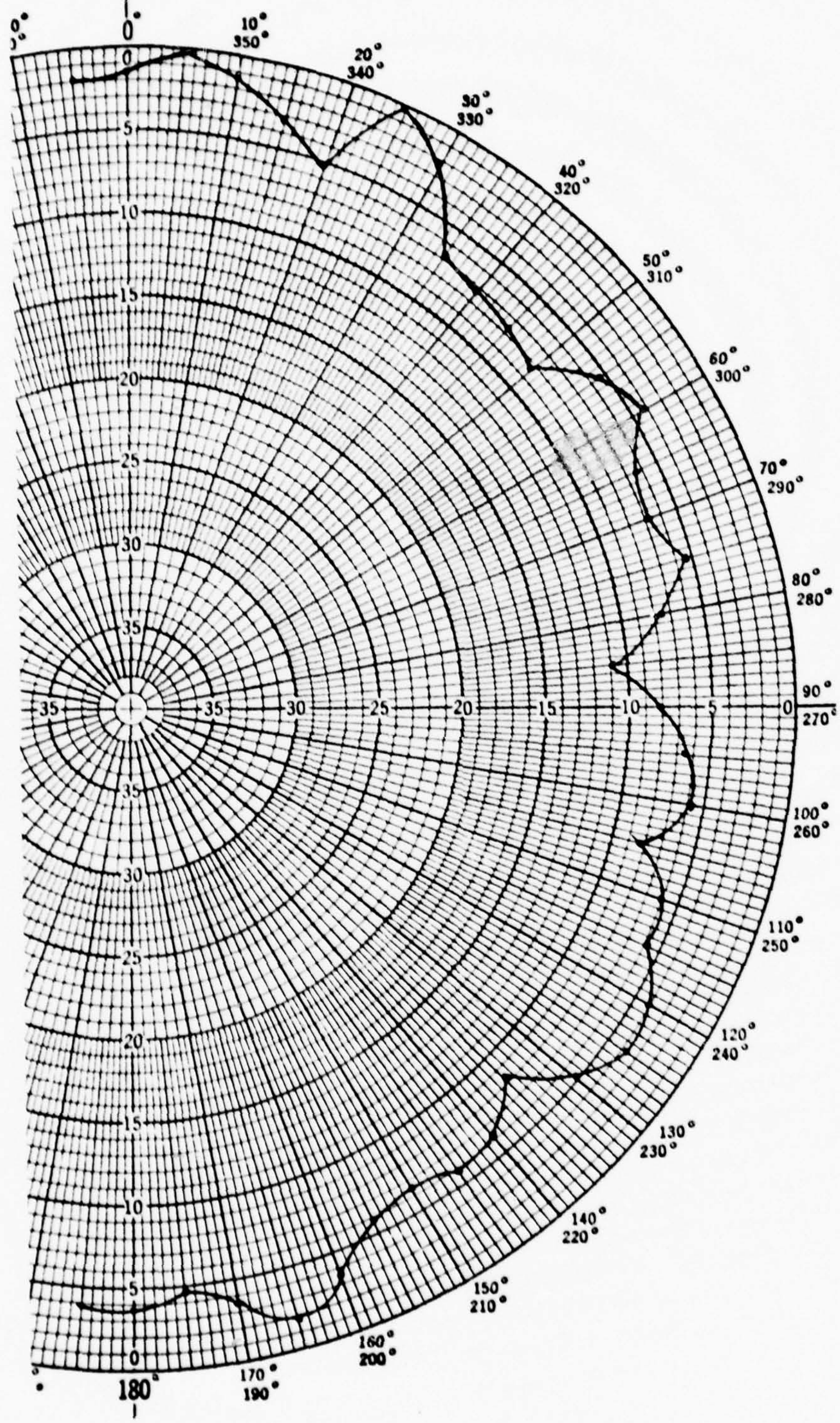


Figure 11A. GTD Pattern from Left-rear Position Taken at 20° Elevation

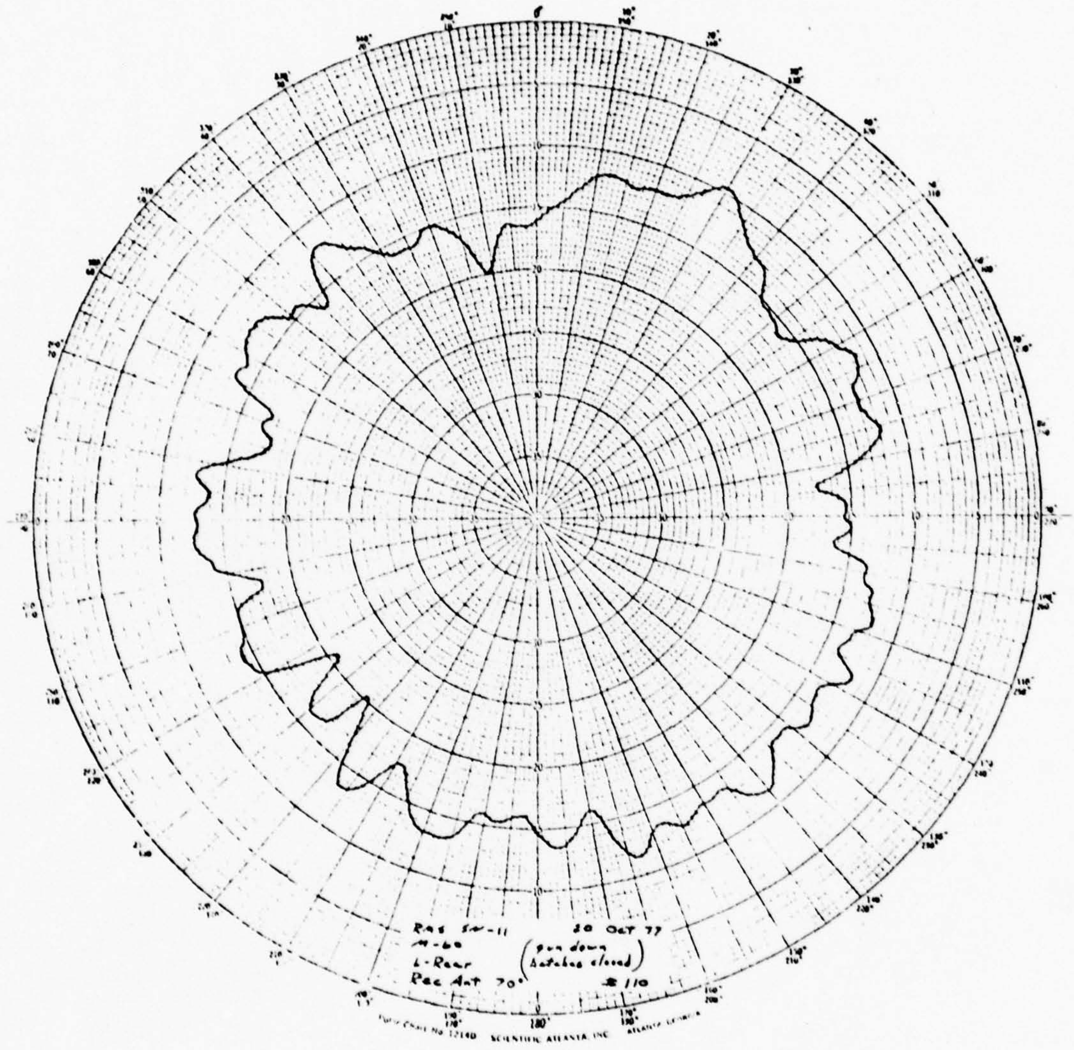


Figure 11B. Actual Antenna Pattern from Left-rear Position
Taken at 20° Elevation

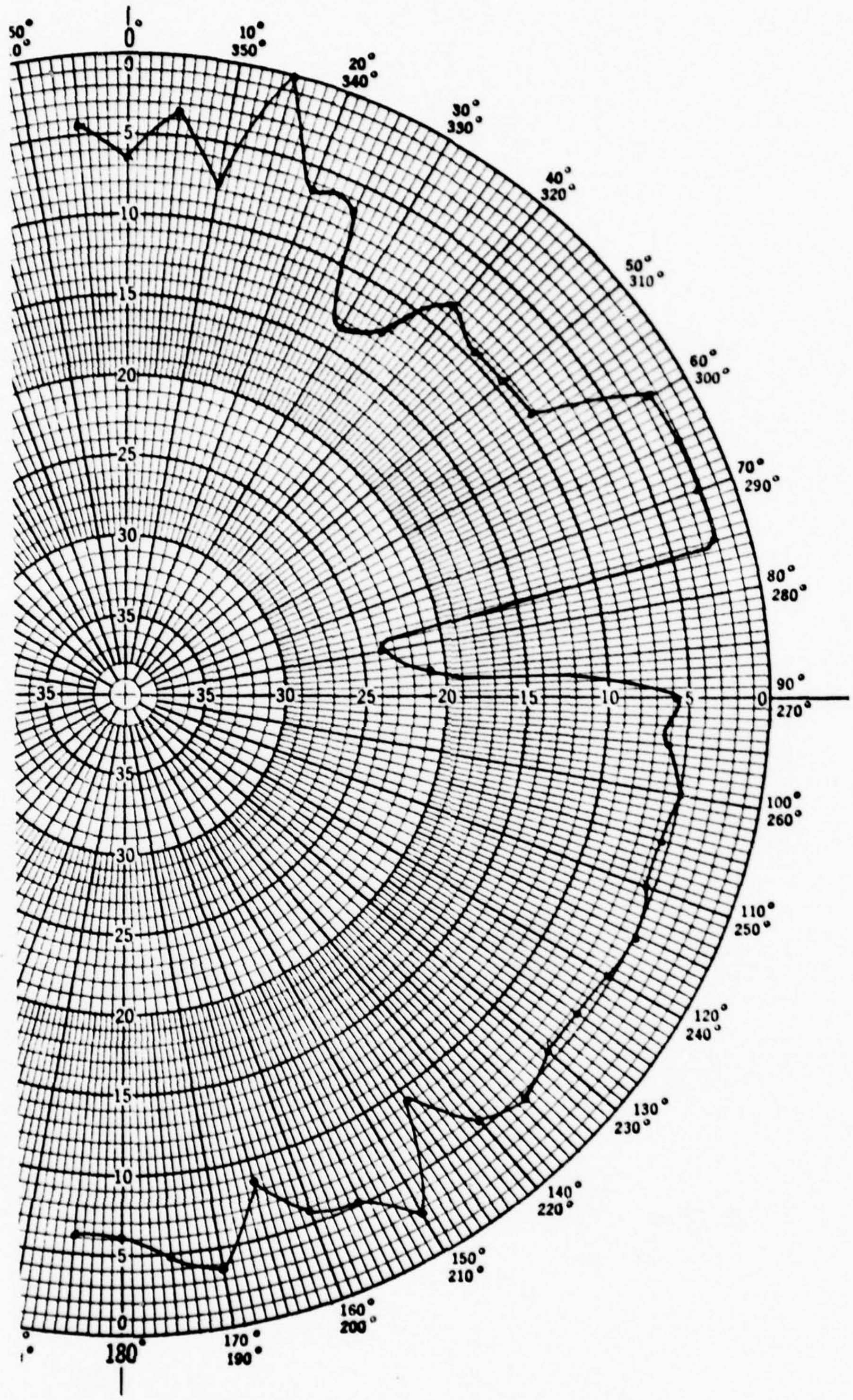


Figure 12A. GTD Pattern from Left-front Position Taken at 0° Elevation

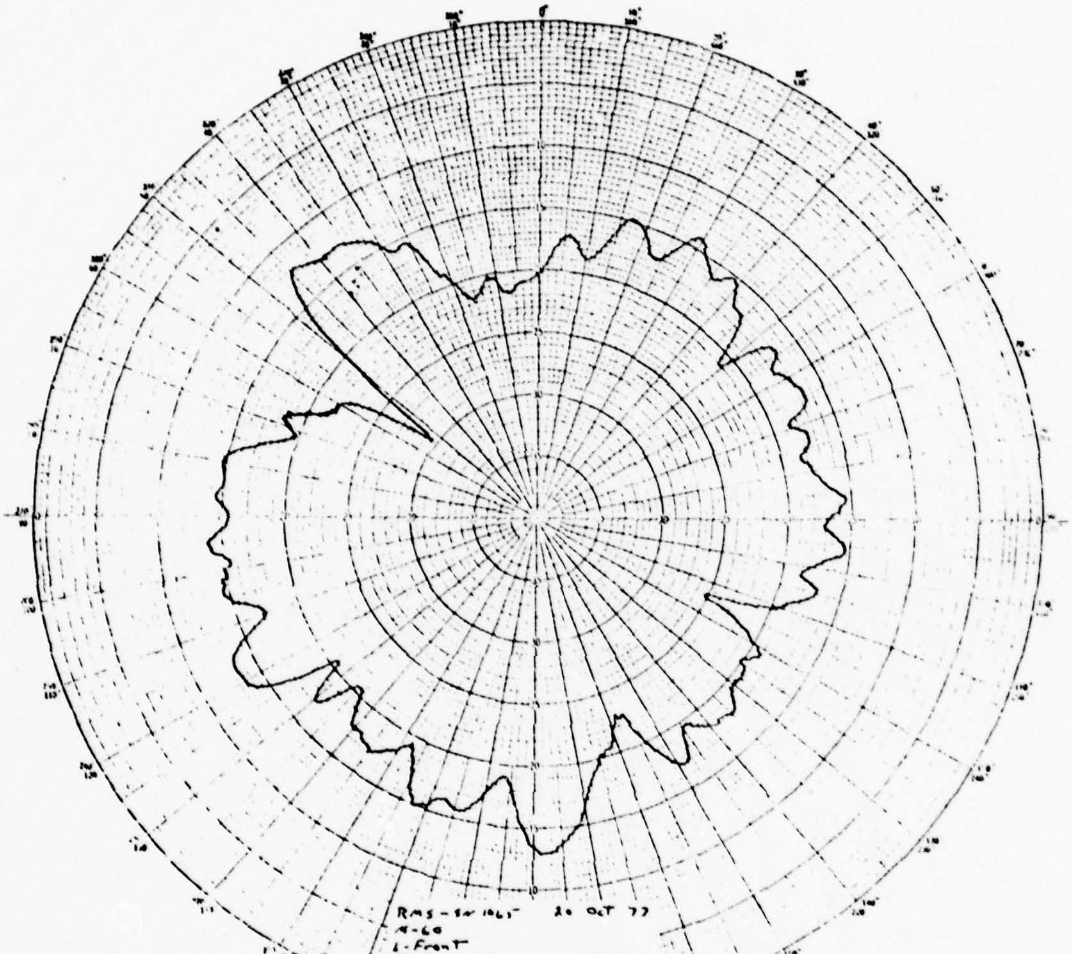


Figure 12B. Actual Antenna Pattern from Left-front Position Taken at 0^{o} Elevation

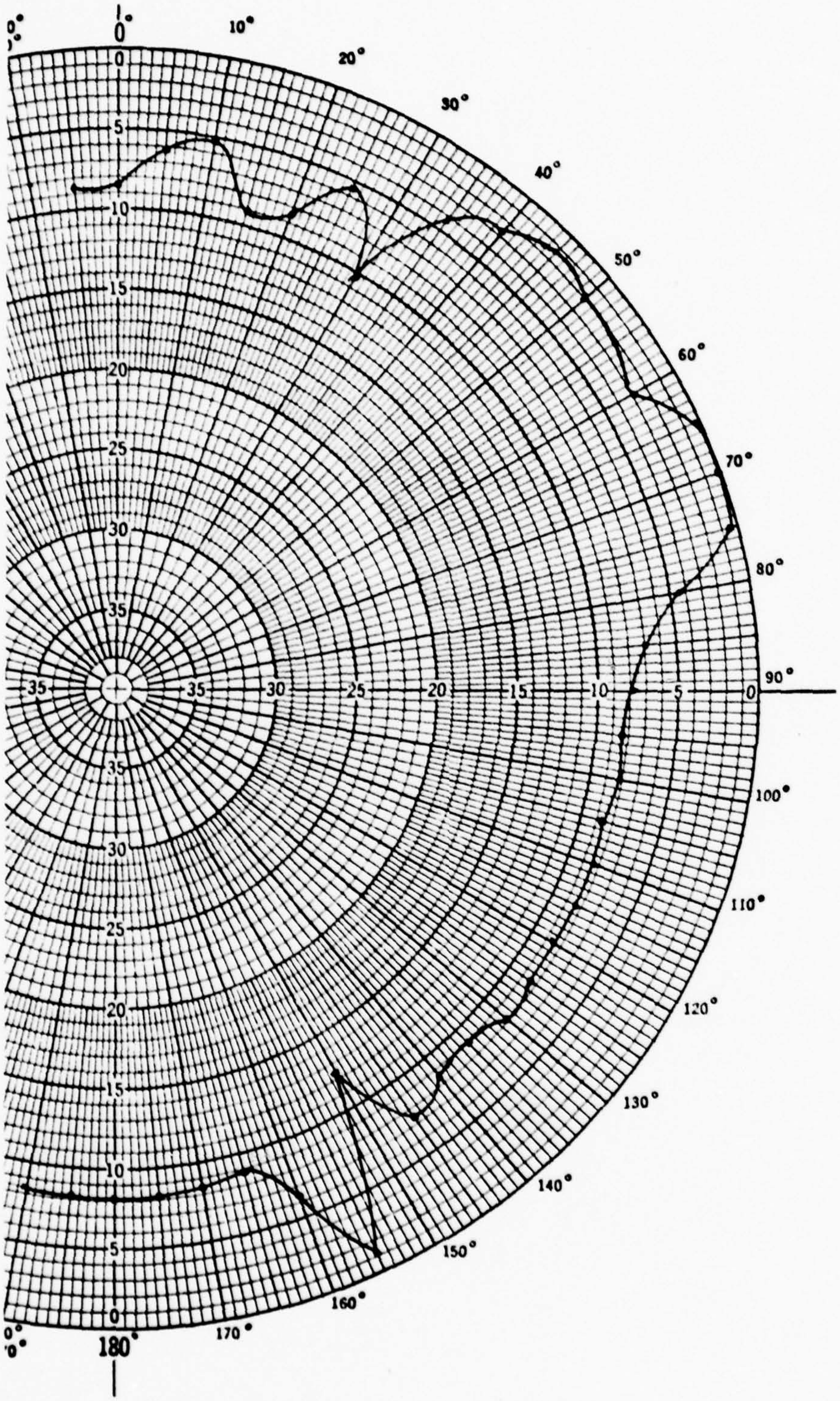


Figure 13A. GTD Pattern from Pallet
Taken at 0° Elevation

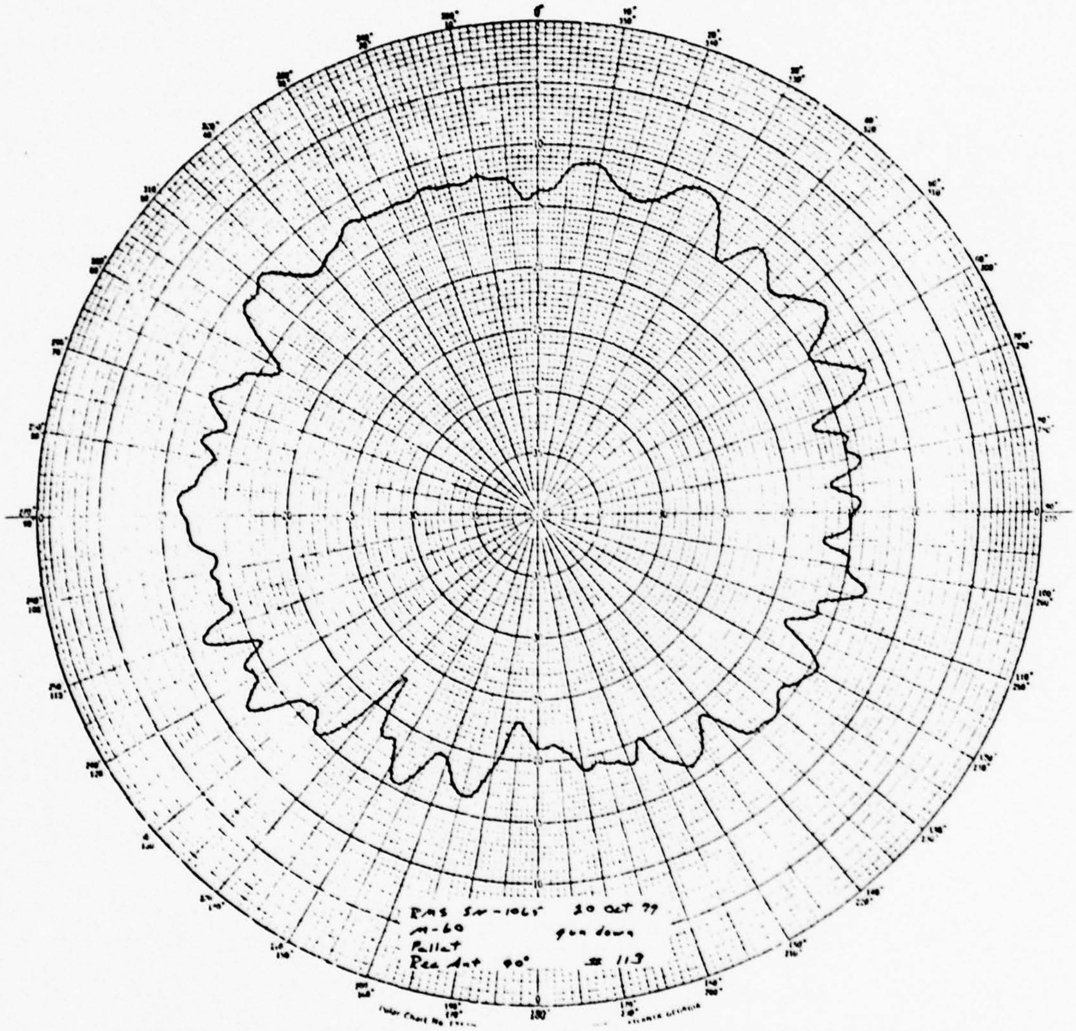


Figure 13B. Actual Antenna Pattern from Pallet
Taken at 0° Elevation

B. RESULTS

1. Antenna Model

It was felt that after the many parameter changes were performed in modeling the antenna a suitable representation was achieved. This model utilized the calculated value for the network loading and satisfied all of the rules and requirements specified in Ref. 6. The antenna current locations and amplitudes appeared correct and the vertical gain pattern accurately represented what the actual pattern should be.

2. Tank Model

Given the limited number of surfaces available in the present GTD program, the tank was modeled as close to the actual vehicle as could be accomplished. As the top of the turret, the cupola and the MIPS pallet utilized all of the fourteen plate surfaces available in the program, several areas of concern could not be included. Therefore, the left 180° of the patterns were not included as they did not represent the tank structure. The patterns did indicate the disturbance created by the cupola and the MIPS pallet due to the short height of the $\lambda/4$ monopole antenna.

3. Antenna Position

The patterns obtained from the GTD programmed $\lambda/4$ monopole were run in the three possible antenna locations on the tank model indicate that the left rear position is the least desirable for the antenna. The left front position also was undesirable as a low profile antenna

would receive considerable disturbance from the cupola and the MIPS pallet causing blind spots at lower elevations. The MIPS pallet was the most desirable location due to its increased height above the turret which compared favorably with the findings in Ref. 11.

The Phelps-Dodge antenna has a definite advantage over the $\lambda/4$ monopole when placed over a large flat ground plane. However, as the Phelps-Dodge antenna patterns have not been accurately evaluated in the complex tank environment, an in-depth comparative analysis of these two antennas may prove beneficial.

IV. CONCLUSIONS

The Phelps-Dodge antenna was modeled to produce radiation patterns that closely simulated the actual antenna and it is believed that it could be effectively utilized as part of the RMS system if positioned on the MIPS pallet. The rugged design of this antenna, coupled with the extremely low initial cost, indicate that it could be a cost effective replacement for the present antenna. A better radiation pattern could be achieved if elevation of the antenna and mounting on a large ground plane were feasible. This could not be accomplished however due to the environment in which the antenna would be employed and terrain encountered at the FHLMR.

This was the initial employment of the GTD program on a complex "real world" problem. The results of the simulation were not completely successful. Previous problems using this code were on simple box or pyramidal-type structures which did not produce the interaction created in this problem. It was discovered that to more effectively model the tank a greater number of surfaces would be required. Due to the program limitation, none of the surfaces below the top of the turret were included. Hence, the interaction of those surfaces were not included in the calculations which caused the patterns on the left side of the tank to be unrealistic because of the proximity of left forward and

left rear antenna positions to the left edge of the turret. The GTD program was unsuccessful in utilizing the seventeen-element AMP model output of the Phelps-Dodge antenna due to the extensive time required to complete the calculations. For the GTD program to be successful on future problems of this size - or larger - either: 1) fewer calculations can be accomplished, thus reducing the accuracy of the resultant patterns; or, 2) the number of antenna segments must be reduced; or, 3) the program converted for use on the NPS Monterey IBM 360/67 system where this investigation would be accomplished without the time and monetary constraints encountered at the NOSC San Diego.

V. RECOMMENDATIONS

To more effectively model a complex structure the GTD program should be expanded to accommodate a greater number of flat surfaces. This would lend greater flexibility to the program and result in greater accuracy. The conversion of the GTD code to the IBM 360/67 digital computer system as well as its expansion is strongly recommended if future research is to be conducted in this area.

In modeling a complex antenna which requires a large number of segments to satisfy the program rules, a method must be devised to reduce the segmented output to as few as possible. One such method would be to convert the envelope produced by the individual segmented current amplitudes and location to half cosines. This could reduce the number of segments significantly. Time limitation precluded further investigation into this possible solution as part of the study. Follow-on research would seem worthwhile to reduce the AMP segmented output.

APPENDIX A
AMP COMPUTER LOG

The AMP Computer Log represents the progression of computer runs indicating errors encountered, corrections made and parameters changed. A small radius - or thin wire - was first run, followed by increased values to monitor the effect this parameter had on the output, as mentioned previously in the text. It can be seen that other parameters were changed also and the portions of the output which were of greatest concern noted in the remarks column.

AMP COMPUTER LOG

Date (1978)	Program Change	Run No.	Remarks
1/9-1/12	AMP 2 (SRC) sample program.	--	AMP 2 (SRC) program options exercised
1/14	Phelps-Dodge 1065A.	1	---
1/14	RP card changed, ϕ=2.	2	Error in RP card
1/15	RP card changed, ϕ=1, θ changed to 1°	3	Error in RP card
	Increased antenna radius to 1/32. . .	4	
	1/16. . .	5	Current increased - vertical power gain pattern remained the same however peaks were lower and nulls higher
	3/32. . .	6	
	1/8 . . .	7	
	5/32. . .	8	
	3/16. . .	9	
	7/32. . .	10	
	1/4 . . .	11	
1/17	3 GW cards, 21 segments, radius 1/32, NT card $_j$150	12	---
	LD card, IND & CAP.	13	Not enough time
	Same run.	14	Very small current values
	LD card, IND & CAP & 10K ohms	15	Very little change
	NT card $_j$1500	16	VSWR 383
	NT card $_j$15	17	VSWR 48
	Straight 21 segment antenna	18	1λ antenna pattern

AMP COMPUTER LOG - Continued

Date (1978)	Program Change	Run No.	Remarks
1/18	Changed normalized gain to vertical, NT $_j$1000, radius 1/16	19	VSWR 471
	NT $_j$2000, radius 1/16.	20	348
	NT $_j$2500	21	328
	NT $_j$150	22	84
	NT $_j$500	23	679
	NT $_j$750	24	559
	No-load - antenna put on ground plane	25	Straight wire, 21 segments
1/19	NT $_j$150, radius 1/16	26	VSWR 1.6
	NT $_j$500	27	1.4
	NT $_j$750	28	4.1
	NT $_j$500, FR 900 MHz.	29	1.2
	908	30	1.2
	928	31	1.7
	936	32	2.0
	NT $_j$400, 918	33	2.0
	NT $_j$600, ...	34	2.5
	NT $_j$500, radius 1/8.	35	VSWR 3.9, Z in high
	1/16	36	3.6, Z = 72 $_j$79
	3/32	37	3.8, Z = 135 $_j$83

AMP COMPUTER LOG - Continued

Date (1978)	Program Change	Run No.	Remarks
1/19	NT $j500$, radius 3/16.	38	VSWR 3.8, Z = 136 $j83$
	5/32.	39	3.9, Z = 115 $j91$
	1/4	40	3.7, Z = 166 $j55$
1/20	NT $j300$, radius 1/8	41	7.1, Z = 315 $-j116$
	5/32.	42	6.3, Z = 255 $-j123$
	Section 2 = 5 segments, NT $j150$, radius 3/16.	43	2.3, Z = 62 $-j48$, wrong feed point
1/23	NT $j300$, radius 1/4	44	
	NT $j150$	45	
	Section 2 = 3 segments.	46	
	NT $j300$, section 2 = 5 segments . . .	47	VSWR 4.9, Z = 157 $-j116$
	NT $j150$	48	VSWR 1.6, Z = 34 $-j14$, violates rule of thumb
	Section 2 = 3 segments.	49	VSWR 2.6, Z = 32 $-j35$
	48 with punch card requested.	50	Current locations for NOSC
	49 with punch card requested.	51	Current locations for NOSC

APPENDIX B
REPRESENTATIVE AMP OUTPUTS AND PATTERNS

Five AMP computer run current distribution, phase angle and vertical gain patterns are included here to illustrate the effects of changing various parameters.

Figure 14A is a 21-segment, 3-section model with $Z = j2500$ ($Y = -4.0 \times 10^{-4}$) as a network load. This load gave a computed antenna input impedance of $Z = 71 - j1079$ and VSWR = 328. This extremely high VSWR value resulted from the large capacitive reactance due to the antenna not being located on the ground plane. The resultant vertical gain pattern (Fig. 14B) shows one main lobe with its maximum value at the horizon.

Figure 15A is a 21-segment model with no-load at the center section gap. This current distribution and vertical gain pattern (Fig. 15B) are like those of a full wavelength antenna. This current distribution pattern was also verified by the thermovision photograph in Fig. 9B. The large disturbance at the antenna base was due to the effects of the driving point. Also the large diameter stainless steel construction of the antenna tends to conduct this heat up the antenna from the base.

Figures 16A and 16B illustrate the run made with a network load of $Z = j500$ ($Y = -j2.0 \times 10^{-3}$). This value yielded an input impedance of $Z = 56 + j18$ and a VSWR = 1.4.

The vertical gain pattern had its main lobe on the horizon with minor lobes at 50° and 25°. The antenna radius however was only 1/32 in.

Figures 17A and 17B are of a 21-segment, 3-section model with $Z = {}_j750$ ($Y = -{}_j1.3 \times 10^{-3}$) load and a radius of 1/32 in. The calculation input impedance for this run was $Z = 73 +{}_j95$ and a VSWR = 4.4. This loading was determined to be too large however the vertical gain pattern had the main lobe on the horizon and one minor lobe at approximately 35°.

Figures 18A and 18B represent the final run made. This model has 17 segments in 3 sections with a network load of $Z = {}_j150$ ($Y = -{}_j6.6 \times 10^{-3}$) and a radius of 1/4 in. Shown is a current distribution which is greatest at the base with a lesser peak at the gap and still smaller current at the top of the antenna. This pattern can also be observed on the thermovision photograph (Fig. 9A). The current is higher at the base, with another peak at the gap and lower on the upper section. Once again the great disturbance at the base is from the driven point as stated above. The computed input impedance was $Z = 32 -{}_j35$, slightly lower than desired but representative of the antenna. The VSWR = 2.6 was also slightly high but within tolerance.

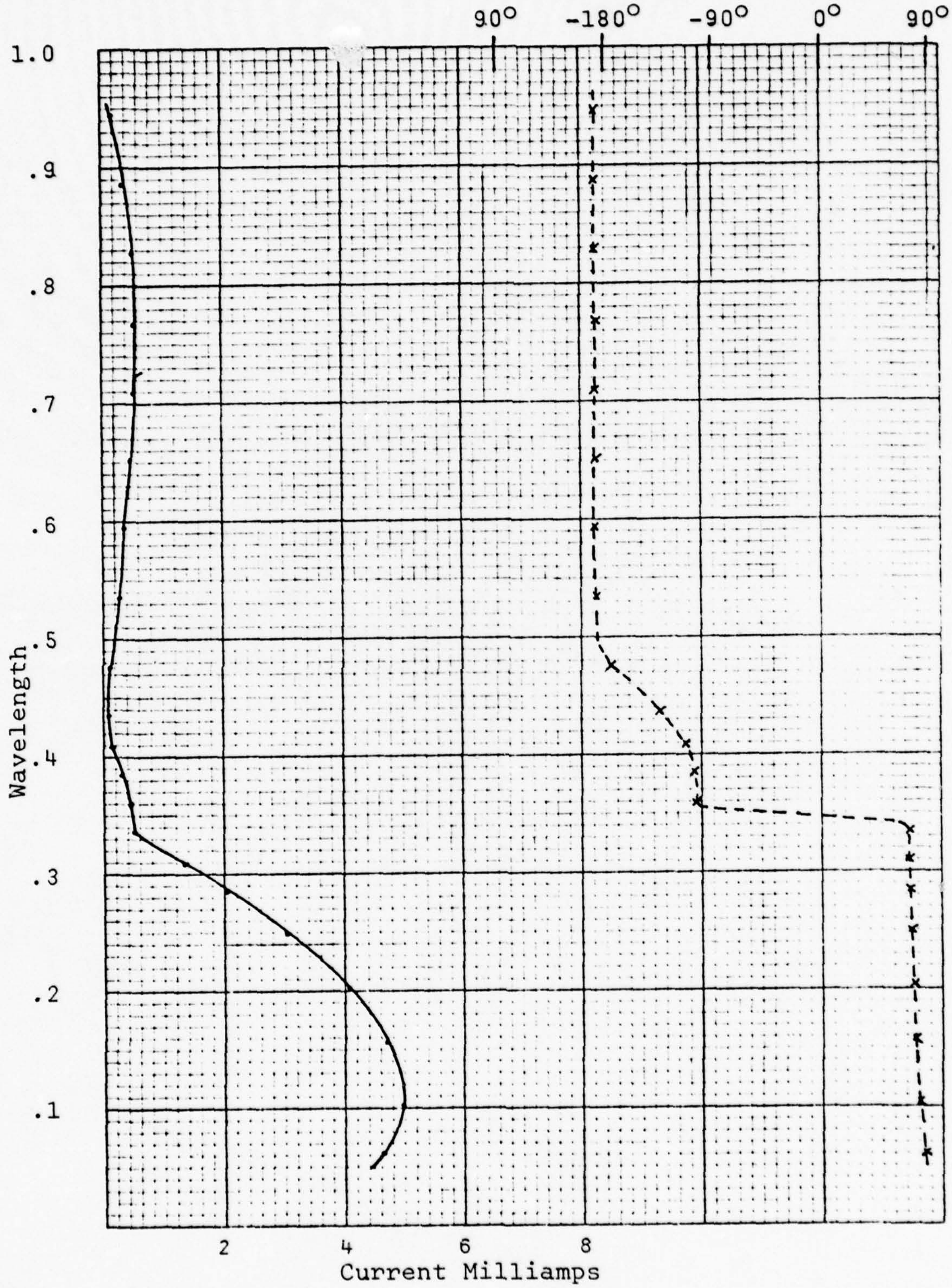


Figure 14A. Current Distribution and Phase Angle of a 21-segment, 3-section Model with Z = $_j$2500 Network Load

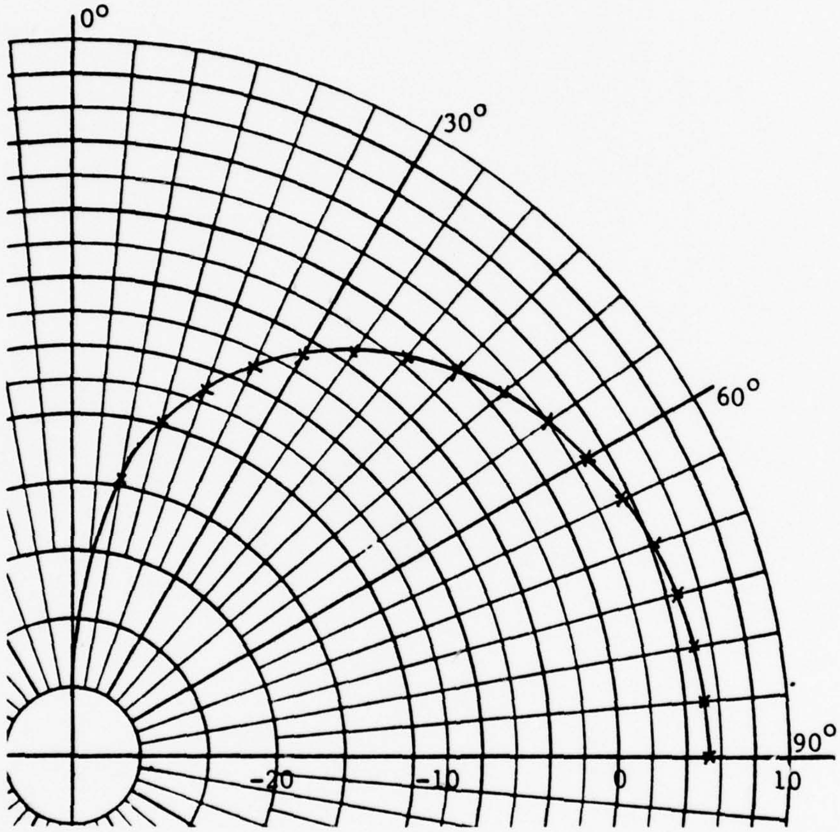


Figure 14B. Resultant Vertical Gain Pattern with $Z = _j2500$ Network Load

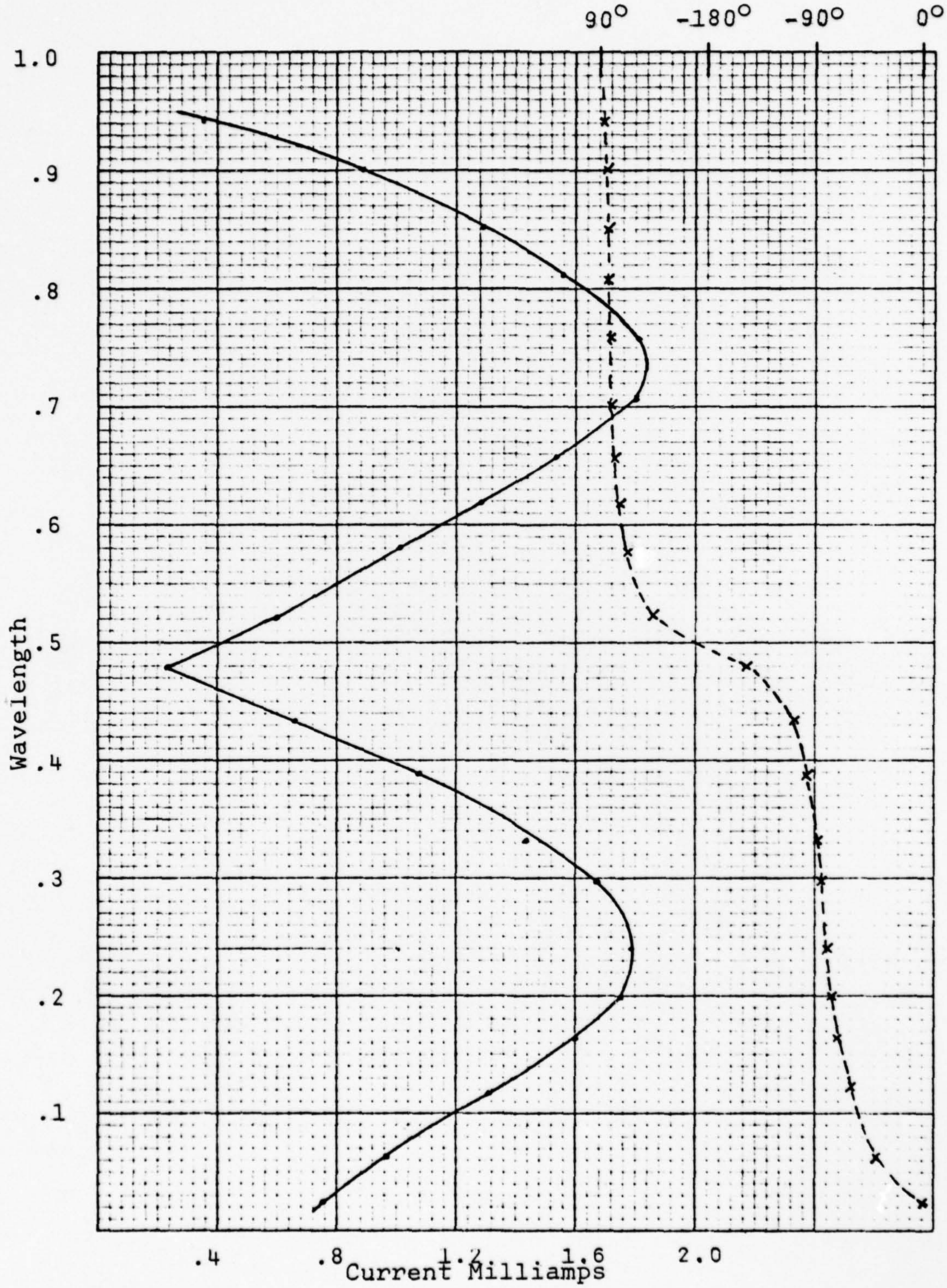


Figure 15A. Current Distribution and Phase Angle of a 21-segment Full Wavelength Model Unloaded

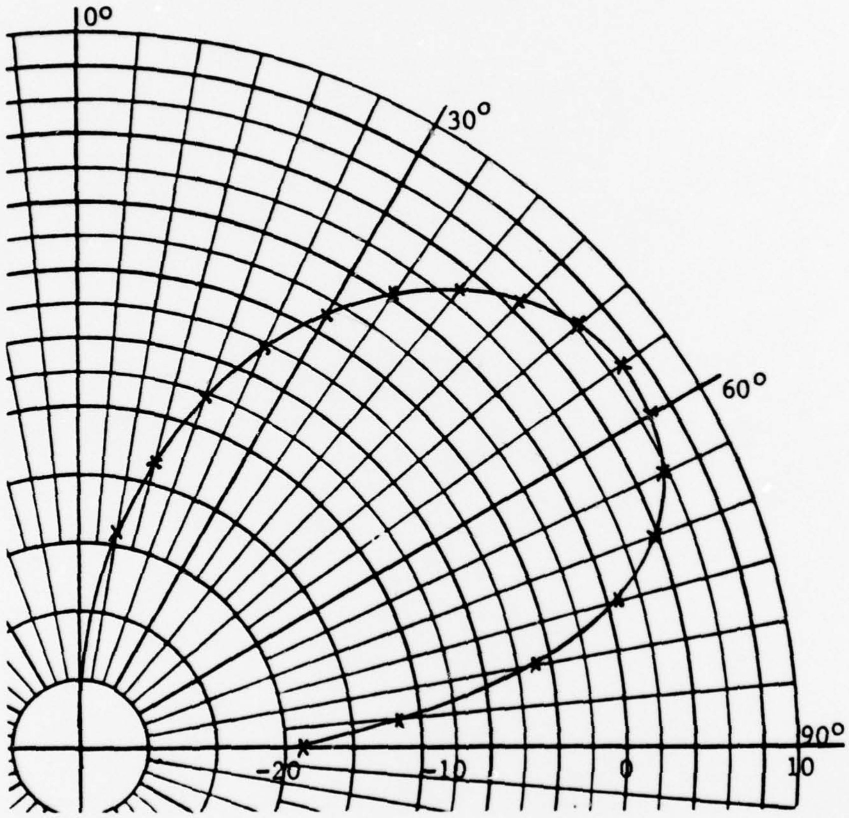


Figure 15B. Resultant Vertical Gain Pattern of Full Wavelength Model Unloaded

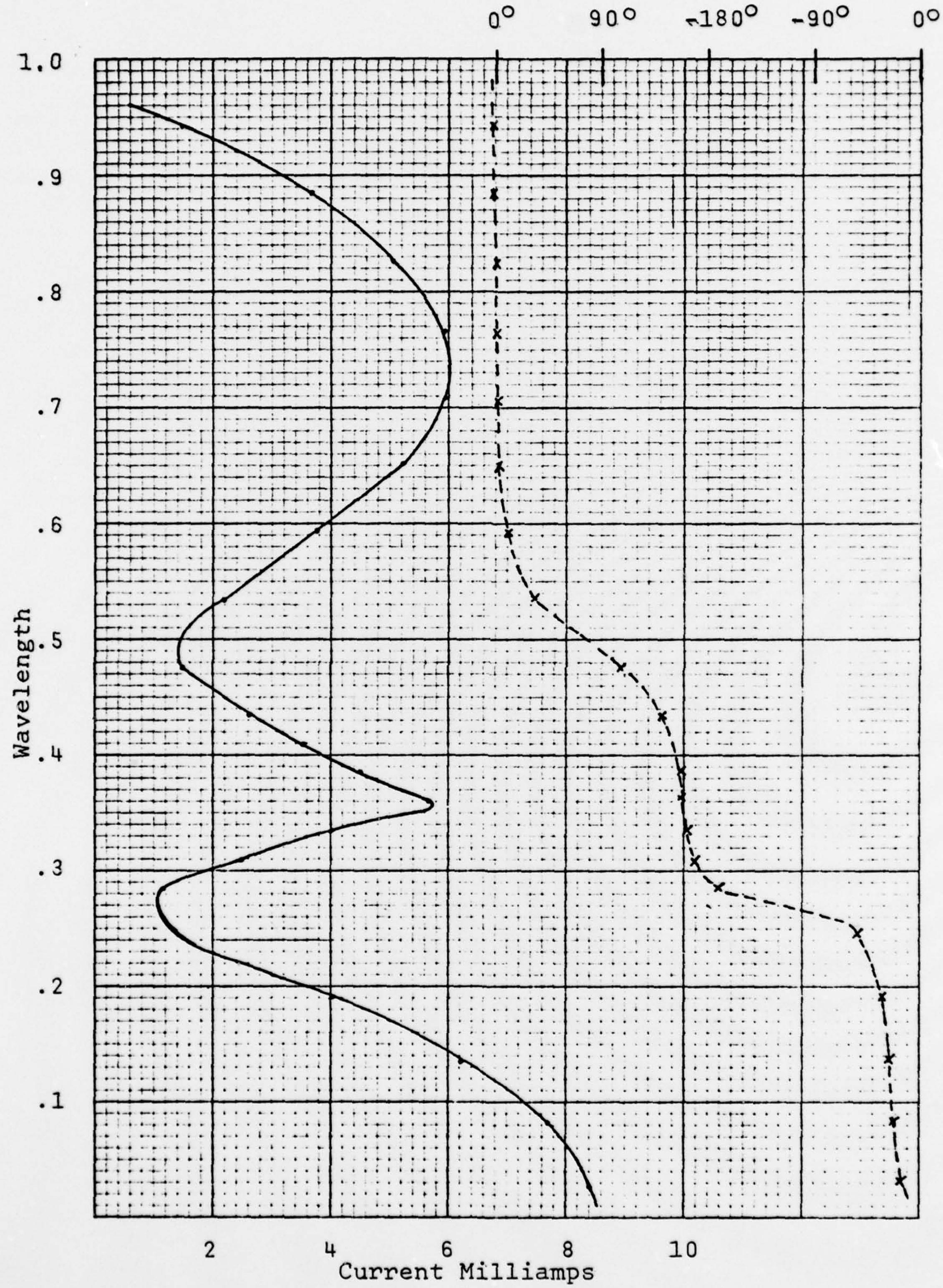


Figure 16A. Current Distribution and Phase Angle of a 21-segment, 3-section Model with $Z = j500$ Network Load & Antenna Radius 1/32 in.

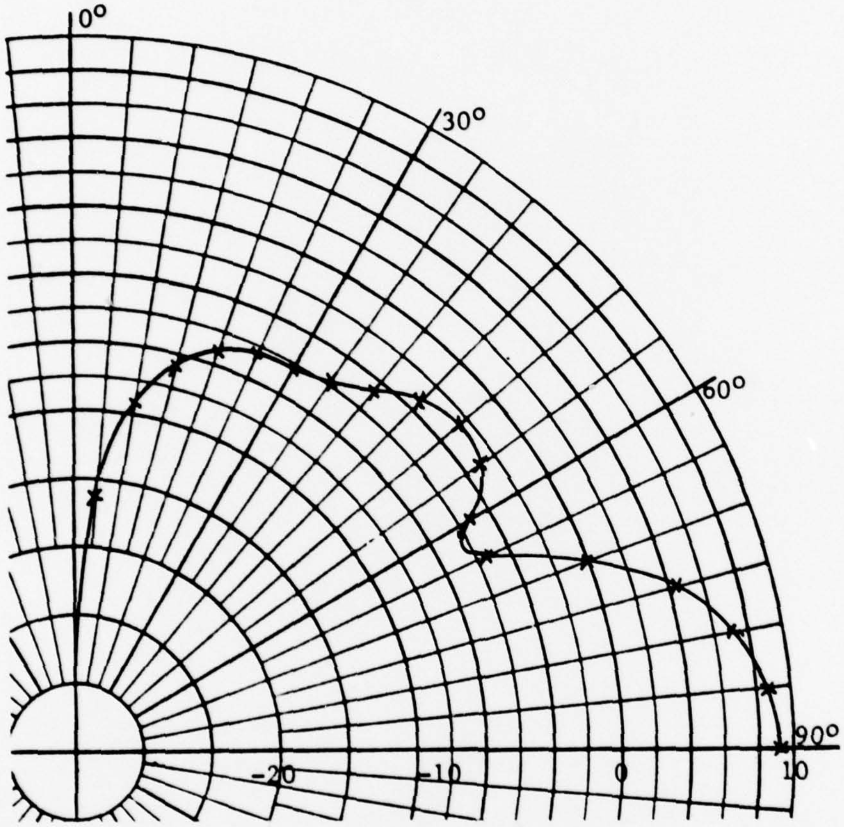


Figure 16B. Resultant Vertical Gain Pattern
with Z = $_j500$ Network Load

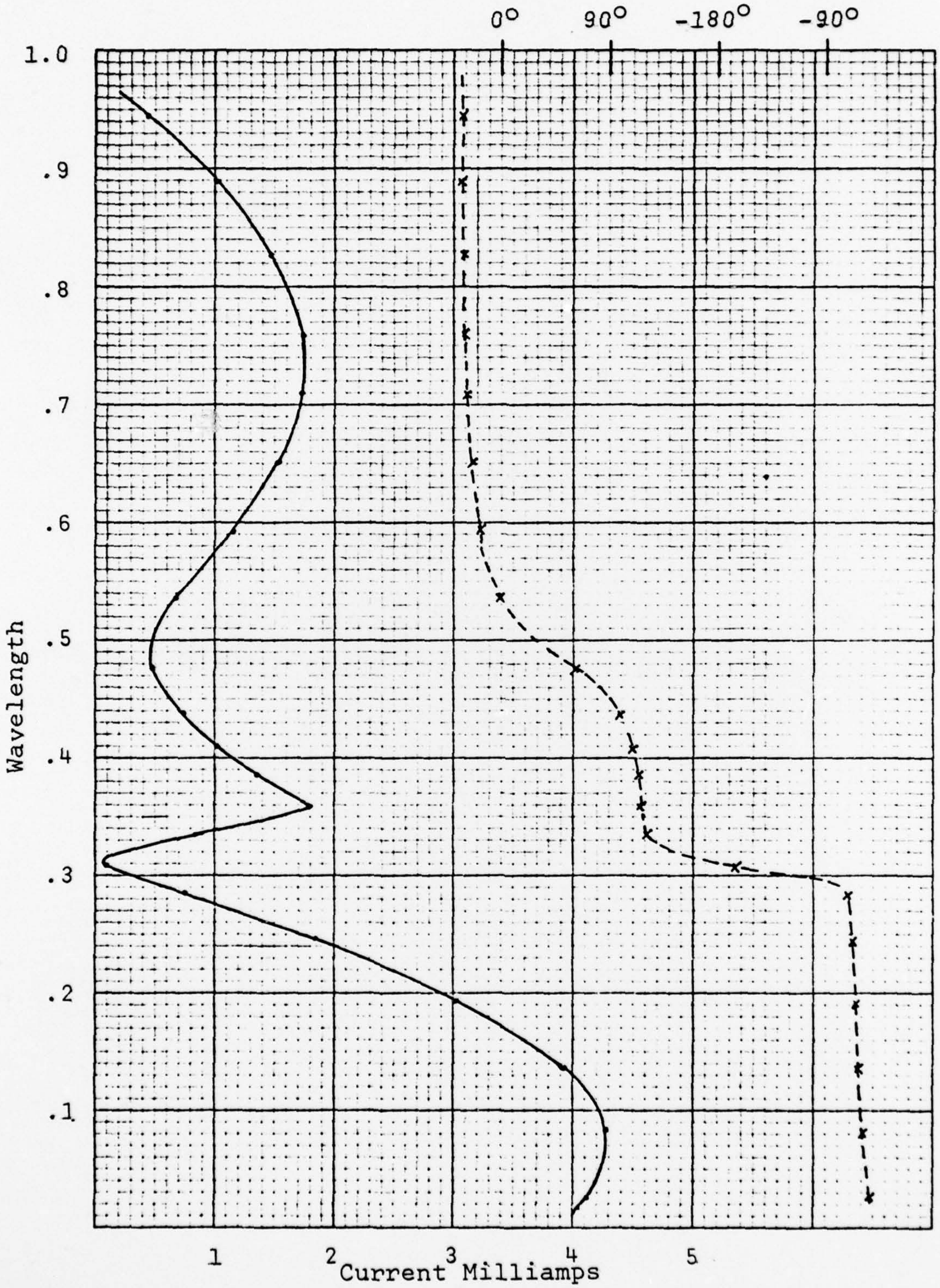


Figure 17A. Current Distribution & Phase Angle of a 21-segment, 3-section Model with Z = -j750 Network Load & Antenna Radius 1/32 in.

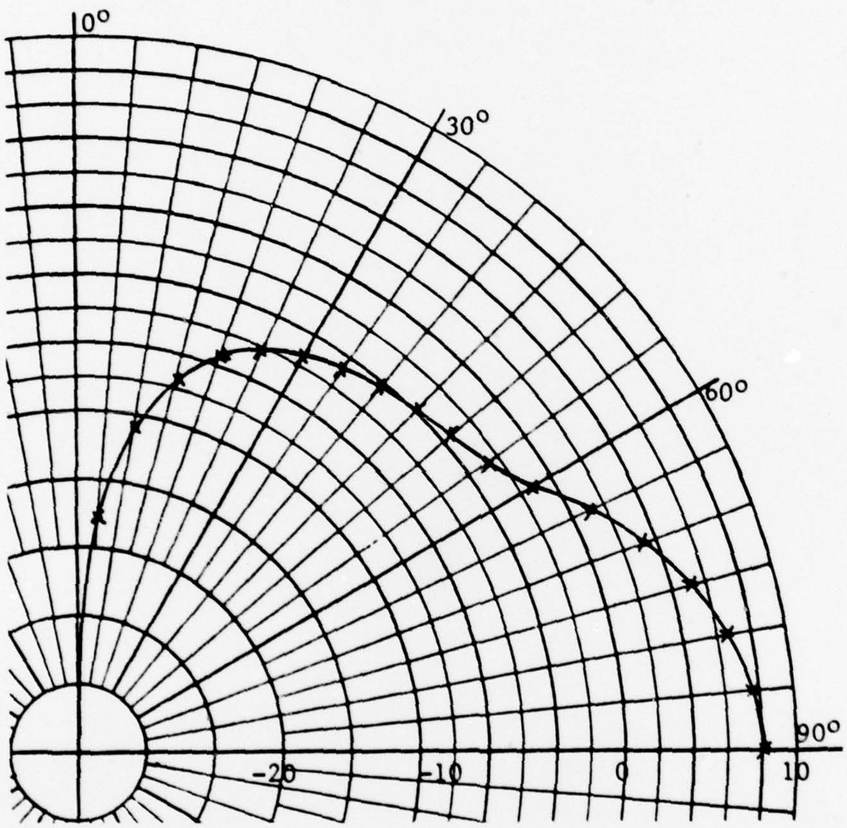


Figure 17B. Resultant Vertical Gain Pattern
with Z = j750 Network Load

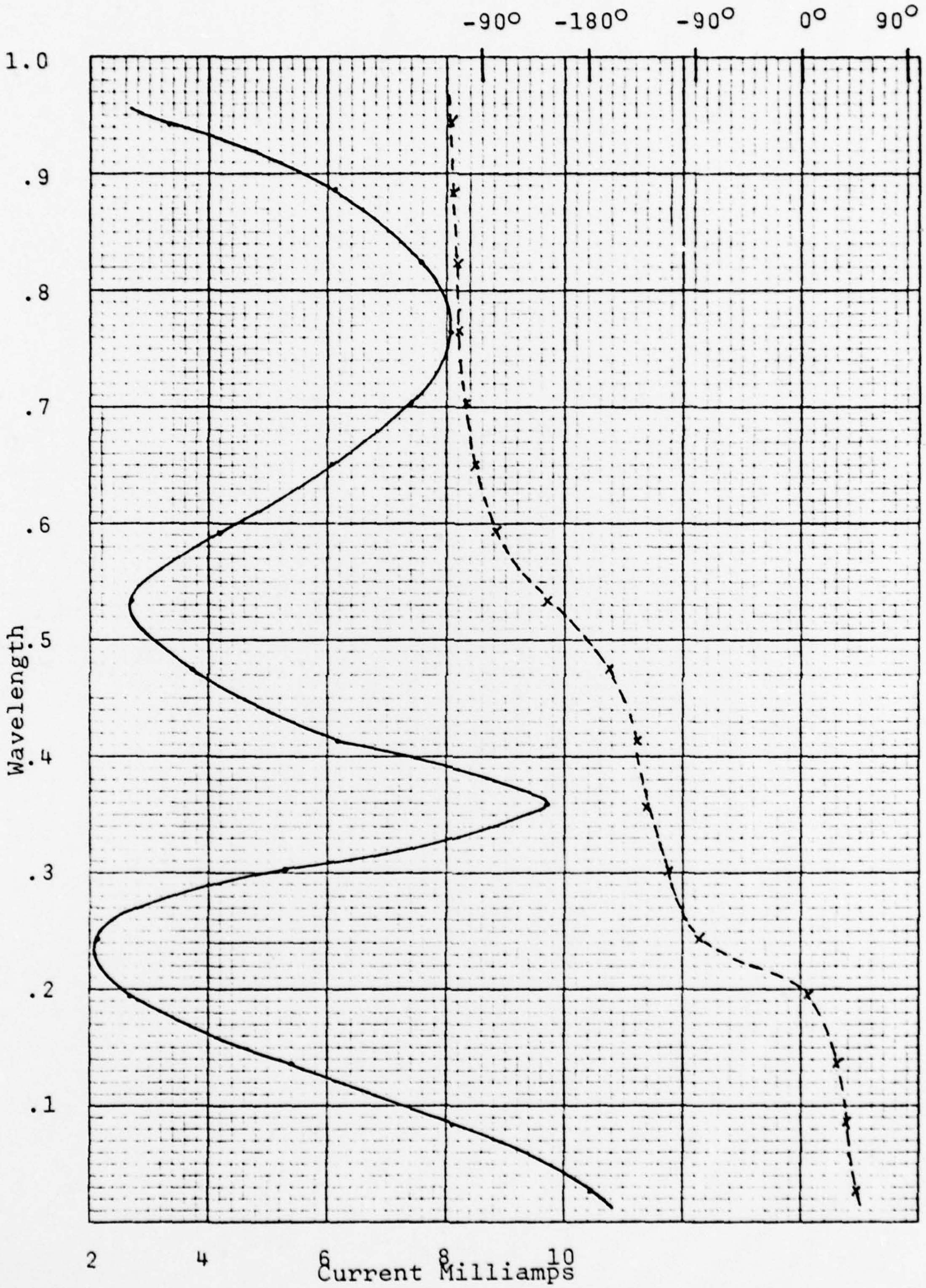


Figure 18A. Current Distribution and Phase Angle of a 17-segment, 3-section Model with Z = j150 and Antenna Radius 1/4 in.

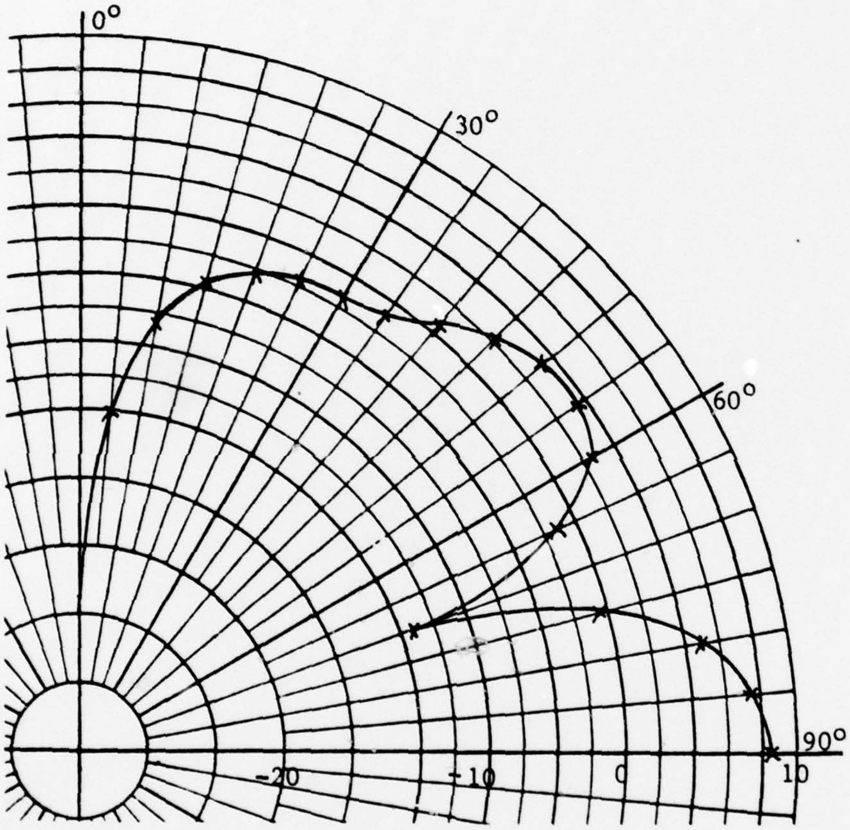


Figure 18B. Resultant Vertical Gain Pattern
with $Z = _j150$ Network Load

APPENDIX C

A sample computer run is included to benefit a future user of the program should the card deck get lost. The AMP program should be on a permanent tape in the NPS Monterey computer library or on disc if in an active status. The run can be divided into five sections for purposes of explanation:

(1) Sections 1 and 4 are the JCL required to run the program and achieve the desired output - see annotation on program.

(2) Section 2 is the object deck for the real and imaginary portions of the program.

(3) Section 3 contains the overlay cards.

(4) Section 5 is made up of the AMP user cards - see Ref. 6 for details on each card.

THIS IS A SAMPLE OF THE AMP PROGRAMS

```
  //MC511814 JOB (1814,0971,HM72),'MCKENZIE SMC 1402',TIME=5
  // EXEC LGO,PARM=(OVLY,MAP,LIST),REGION=350K
1 //LINK.INPUT DD DSNAME=S1814.AMP2(SRC),DISP=SHR,UNIT=3330,
  //   VOL=SER=DISK03
  //LINK.SYSIN DD *
  BESD        &    ADREAL                                                   DREA0001
  BTXT    Y   8    A                +                  +                    DREA0002
  BTXT        0    AGOO<FDREAL   &%&<QTOYQ(Q&OU&& H&4& G2                   DREA0003
  BTXT    -   8    AQ-& K|&Y- G E-QO-FG3    Q&&DQ&&QQ-& K|- &YY &-Q&&DQ-&<Q%DREA0004
  BTXT   AC   Q    A&*K"&<G=Y &Y- &-$"Q&& G1                                DREA0005
  BTXT    &   &    A   0  &-  -&  C                                         CREA0006
  BTXT    4   D    A  A-                                                    DREA0007
  BTXT    %   D    A   8                                                    DREA0008
  BTXT    Y   D    A   -                                                    CREA0009
  BTXT    U   D    A   0                                                    DREA0010
  BRLD        U      A A(  @(   (  D(  4(  %(  Y(  U<  8                    DREA0011
  BEND                             AO                                       DREA0012
2 BESD        &    ADIMAG                                                   DIMA0001
  BTXT    &   8    A                +                  +                    DIMA0002
  BTXT        0    AGOO<FDIMAG   &%&<QTOYQ(Q&OU&& H&4& G2                   DIMA0003
  BTXT    0   8    AQ-& K|&8- G E-CO-FG3    Q&&DQ&&QQ-& K|- &8Y &OQ&&DQ-&<Q%DIMA0004
  BTXT   AY   Y    A&*K"&<G=Y &8Y-& - &---&YY &Y- &O$"Q&& G1                CIMA0005
  BTXT    8   &    A   0  &-  -&  0                                         DIMA0006
  BTXT   AC   D    A  AO                                                    DIMA0007
  BTXT    %   D    A  AH                                                    DIMA0008
  BTXT    Y   D    A   0                                                    DIMACCC9
  BTXT    L   D    A   0                                                    CIMA0010
  BRLD        U      A A(  @(   (  D( AD(  %(  Y(  U<  8                    DIMA0011
  BEND                             A&                                       DIMA0012
   INCLUDE INPUT(SRC)
   ENTRY MAIN
   OVERLAY A
   INSERT READ
   INSERT NUMBER
   INSERT DATAGN
   INSERT ARC
   INSERT WIRE
   INSERT GRID
   INSERT REFLC
   INSERT PATCH
   INSERT MOVE
   INSERT CONECT
```

```
      INSERT  CONVRT
      INSERT  HELIX
      INSERT  FBLOCK
      OVERLAY A
      INSERT  LOAD
      INSERT  PRNT
      INSERT  ZINT
      OVERLAY A
      INSERT  HFLD
      INSERT  EFLD
      INSERT  INTX
      INSERT  GN
      INSERT  GH
      INSERT  HFK
      OVERLAY B
      INSERT  NEFLD
      INSERT  NHFLD
      INSERT  NRFLD
      OVERLAY B
      INSERT  COUPLE
      INSERT  CABC
      INSERT  CMSET
      INSERT  TRIO
      INSERT  JUNC
3     INSERT  MATFIL
      INSERT  JMELS
      INSERT  APRXE
      INSERT  APRXH
      INSERT  HINTG
      INSERT  HMAT
      INSERT  HWMAT
      INSERT  PCINT
      INSERT  UDOTES
      INSERT  UNERE
      INSERT  INTG
      OVERLAY A
      INSERT  FACTRC
      INSERT  FACTRS
      INSERT  SUB1
      INSERT  FACIO
      INSERT  LFACTR
      INSERT  SUB2
      INSERT  LUNSCR
      INSERT  ETMNS
      INSERT  SOURCE
      INSERT  FUNCT
      INSERT  ELPING
      OVERLAY A
```

```
INSERT MTSOLV
INSERT NETWK
INSERT SOLVEC
INSERT VSWR
INSERT SOLVES
INSERT LTSOLV
OVERLAY A
INSERT PATERN
INSERT FFLDS
INSERT EFUN
INSERT FFLD
INSERT GFLD
INSERT GWAVE
   ENTRY MAIN

        DELIMITER CARD (/*) GOES HERE
```

4

```
//GO.FT08F001 DD SYSOUT=B
//GO.FT11F001 DD UNIT=SYSDA,SPACE=(CYL,(1,1)),
//         DCB=(RECFM=VS,BLKSIZE=2000)
//GO.FT12F001 DD UNIT=SYSDA,SPACE=(CYL,(1,1)),
//         DCB=(RECFM=VS,BLKSIZE=2000)
//GO.FT13F001 DD UNIT=SYSDA,SPACE=(CYL,(1,1)),
//         DCB=(RECFM=VS,BLKSIZE=2000)
//GO.FT14F001 DD UNIT=SYSDA,SPACE=(CYL,(1,1)),
//         DCB=(RECFM=VS,BLKSIZE=2000)
//GO.FT15F001 DD UNIT=SYSDA,SPACE=(CYL,(1,1)),
//         DCB=(RECFM=VS,BLKSIZE=2000)
//GO.FT16F001 DD UNIT=SYSDA,SPACE=(CYL,(1,1)),
//         DCB=(RECFM=VS,BLKSIZE=2000)
//GO.FT17F001 DD DUMMY
//GO.SYSIN DD *
```

5

```
CM PHELPS DODGE VERTICALLY POLARIZED ANTENNA
CM APPROXIMATLY ONE WAVELENGTH LONG
CM TOP SECTION ABOUT 5/8 WAVELENGTH LONG
CM BOTTOM SECTION ABOUT 3/8 WAVELENGTH LONG
CE CONDUCTOR DIA= 1/2 IN
GW,1,5,0.0,0.0,0.0,0.0,0.0,2.9167E-1,.021
GW,2,3,0.0,0.0,2.9167E-1,0.0,0.0,0.47917,.021
GW,3,9,0.0,0.0,0.47917,0.0,0.0,1.04167,.021
GS,2,0.304801
GE,1,001
GN,1
FR,0,0,0,0,918.0
NT,2,2,3,9,0.0,-6.6E-3,0.0,0.0,1.0E+10,0.0
EX,0,1,1,11,0.5
RP,0,91,1,1300,90.0,0.0,-1.0,0.0
EN
```

LIST OF REFERENCES

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2. Braddock, Dunn & McDonald Scientific Support Laboratory, Report TSP-0764-75, RMS Evaluation Final Report, by T. S. Penfound, 30 May 1975.

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